EVALUATION OF ARGENTINE MAIZE HYBRIDS AND EXOTIC X TEMPERATE TESTCROSSES ACROSS ENVIRONMENTS

A Thesis

by

BRETT A. OCHS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2005

Major Subject: Plant Breeding

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Approved by:

Chair of Committee,	F. Javier Betrán
Committee Members,	William L. Rooney
	Tom Isakeit
Head of Department,	C. Wayne Smith

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ABSTRACT

Evaluation of Argentine Maize Hybrids and Exotic x Temperate Testcrosses Across Environments. (August 2005)

Brett A. Ochs,

B.S., University of Illinois

Chair of Advisory Committee: Dr. F. Javier Betrán

Maize (*Zea mays* L.) is grown in a wide range of environments and altitudes worldwide. Maize has transitioned from open pollinated varieties to single cross hybrids over the last century. While maize production and genetic gain has increased, genetic diversity among U.S. maize hybrids has narrowed. Problems, such as insect pressure, diseases, and mycotoxins, present obstacles for breeders. One approach is to use exotic germplasm in breeding programs to provide useful, novel alleles for productivity, grain quality, and disease resistance. Little exotic germplasm has been used, because of lack of agronomic adaptation and problems with lodging, earliness, and tall plants in more temperate areas. Using exotic elite materials and evaluating them in targeted regions might increase success. Objectives of this research were: to characterize and evaluate agronomic adaptation and performance of Argentine commercial hybrids in the U.S., to evaluate semi-exotic testcrosses developed from semi adapted 100% tropical lines and elite U.S. inbred LH195, and to estimate response to aflatoxin contamination of Argentine hybrids and semi-exotic testcrosses under inoculation with *Aspergillus flavus*.

Agronomic data was collected during 2004 in eleven Texas environments for Argentine hybrids, and eight Texas environments for semi-exotic testcrosses. Response to aflatoxin was measured in three southern Texas environments. U.S. commercial hybrids were used as checks. Significant differences among hybrids were observed for most environments and traits. In general, Argentine hybrids yielded lower, had lower 1000 kernel weights, and greater test weights than U.S. hybrids. Hybrids AX889, AX882MG, and AX890MG were competitive with U.S. hybrids for grain yield and were stable across environments. Semi-exotic testcrosses had similar lodging and grain moisture percentages, heavier test weights and competitive grain yields compared with U.S. hybrids. Hybrid TX-LAMA2002-9-2-B/lH195 had the highest overall grain yield mean for semi-exotic testcrosses and yielded better than two U.S. hybrids. Argentine hybrids had lower aflatoxin concentration than U.S. hybrids; several hybrids had less than 50 ng g^{-1} aflatoxin. Semi-exotic testcrosses had reduced aflatoxin compared to U.S. hybrids, with several hybrids under 35 ng g^{-1}. These elite, exotic materials show promise for breeding programs, with competitiveness for grain yield, kernel traits, and reduced aflatoxin levels.

DEDICATION

This thesis is dedicated to all the family and friends that have been supportive of my education. To my mother, Mary, thanks for pushing me in school and allowing me to choose my paths through life. To my father, Dennis, thanks for instilling work ethic and values in me and for raising me on the family farm.

To my friends who were taken from this earth prematurely and didn't have a chance to pursue their dreams, I am grateful for the time we had together.

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Thanks to Daniel Novoa for providing Argentine commercial hybrid maize seed for this experiment.

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CHAPTER I

INTRODUCTION

Maize (*Zea mays* L.) is an important crop both in the United States and worldwide. In the U.S. maize grain is primarily used for livestock feed, but is also present in many food products, and has many industrial uses such as ethanol and polymer production. In the U.S. the majority of maize production takes place in the Midwest states including Nebraska, Iowa, Illinois, Indiana, and parts of Ohio (also known as the Corn Belt), but maize is grown in many areas throughout the world. In 2004, U.S. maize grain production was estimated at 11.8 billion bushels, and 160.4 bushels per acre, both production figures are the largest on record (NCGA, 2005). Texas maize acreage in 2004 was 1,830,000 acres planted, and 1,680,000 acres harvested (NCGA, 2005). Maize producers in Texas averaged 139 bushels per acre and total state production was 233,520,000 bushels, substantially higher than recent years (USDA NASS, 2005).

Maize has many uses aside from feedstuffs for livestock and consumption by humans. Maize has been utilized in recent years for fuel alcohol, penicillin production, food and beverage mixes, recycled paper, intravenous solutions, and high fructose corn syrup found in soft drinks (Texas Corn Producers, 2005). Much research is currently taking place for new uses of maize and how to reduce reliance on petrochemicals by

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This thesis follows the style of Crop Science.

using natural, renewable compounds from maize. Maize can also be grown for harvest of biomass, which is then used for forage or even energy production.

Maize is a species believed to have evolved from teosinte (*Zea mexicana*). In the last century we have witnessed tremendous gains in grain yield and a switch from production of open pollinated cultivars to single cross hybrids. Spacing between plants has decreased in commercial production and new hybrids have reduced barrenness at high populations. Tassel size has been reduced and plants respond well to increased fertility and pesticide use.

With concerns about reduced genetic diversity in U.S. temperate maize and the effect on maize productivity and potential gain, breeders have looked for other germplasm to incorporate into programs of maize improvement. One of the first steps to determine if the material has potential for use in maize improvement is to evaluate and characterize the material to determine performance across a wide range of environments. This thesis presents three experiments conducted during the summer of 2004 in different maize producing environments in Texas, in order to determine the usefulness of two different types of exotic maize germplasm. One experiment evaluated commercial maize hybrids from Argentina in eleven different environments for agronomic adaptation, grain yield, and grain quality traits. The second experiment evaluated semi exotic testcrosses, temperate adapted 100% tropical lines crossed with elite U.S. temperate inbred LH195, across seven different environments for grain yield and agronomic traits, The third experiment used materials from both studies to look at aflatoxin response under inoculation with *Aspergillus flavus* in three southern Texas environments conducive for aflatoxin contamination of maize grain.

CHAPTER II

LITERATURE REVIEW

Maize

Origins, Distribution, and Adaptation

The exact location of maize origin is not known, but maize is believed to have originated in Central America, probably somewhere in Mexico over 6,000 years ago (Wilkes, 2004). Mexico and Guatemala have the most diverse distribution of maize, teosinte, and the related genus *Tripsacum*. Maize spread out from there, and by the time Columbus sailed to the New World, maize was cultivated from Canada to South America and everywhere in between (Wilkes, 2004). Maize is now found in almost every country in the world and has become a staple in the diet of millions of people.

The maize produced throughout the world hardly resembles teosinte anymore, as maize produces cobs with tightly bound seeds that cannot survive without human intervention or dispersal(Wilkes, 2004). Flowering dates have also been reduced as teosinte flowers over periods of 4 or 5 weeks, but modern maize flowering period is less than 10 days, however, full fertile crosses between the two are still possible and can be found in the wild or produced by artificial hybridization (Doebley, 1994; Galinat, 1988; Wilkes, 2004).

Maize is found throughout the world now and there are estimated to be 300 different races, 250 of those in South America (Goodman and Brown, 1988; Holland and Goodman, 1995; Wilkes, 2004). There is much variation between the different races. In the U.S., up to ten different races have given way to hybrid maize. Race Corn Belt Dent were at one time the dominating race (Goodman and Brown, 1988). Some of the inbreds that began the progress of hybrid maize were developed from these materials.

Importance of Maize

Maize is the number one cereal grain produced worldwide, with wheat then rice following behind in production numbers (FAO, 2005). Maize is found in many different food items, as well as being a major source of food for livestock, and in parts of the world makes up much of the diet. In addition maize is involved in many industrial uses ranging from polymer production, starch production, and also for fuels and lubricants.

In 2003, one fifth of maize raised in the U.S. was exported, a total of 47.7 million metric tons, or $4.5 billion dollars worth (NCGA, 2004). Agricultural exports are very important to the U.S. and maize exports support a favorable trade balance. The U.S. is by far the leading exporter of maize grain, but other countries such as Argentina, Brazil, and China are increasing both maize production and exports.

Maize Production

In the United States harvested maize acreage is a close second to soybean acreage, but due to higher maize grain yields per acre maize production levels are far higher than soybean. In fact, maize grain production was more than 7,500,000,000 bushels above than soybean seed production in the U.S. in 2004 (USDA NASS, 2005). Due to increased rainfall and optimal growing conditions, 2004 was a record setting year for maize production. The U.S. is the world's biggest producer of maize, followed by

China, Brazil, and Mexico, but those three countries combined don't produce as much maize grain as the U.S. per year (FAO, 2005).

While maize has underwent great increases in production and genetic gain over the last century due to changes in agronomic practices and plant breeding, concerns have been raised about the narrowing genetic diversity of temperate maize grown in the U.S.

Genetic Diversity

Only recently, in the 1960's, were widespread concerns raised about the genetic diversity of many of the crops grown throughout the world (Simmonds, 1993). While over 300 different races of maize are found throughout the world, only 1 race is commonly grown within the U.S. Corn Belt. This also holds true for germplasm, of which there are many different sources worldwide for maize germplasm, but in the U.S. only a few cultivars were used to develop the germplasm used in the majority of commercial hybrids (Troyer, 2004). By increasing genetic diversity available in U.S. temperate maize, long-term genetic gain can be maintained and alleles for quality traits, disease and insect resistance, and productivity may be found. One way to immediately add diversity to maize germplasm is to look for exotic sources of maize germplasm with unique alleles for adaptation, grain yield and quality.

Genetic variation is important to maize and other crop breeders because selection from pools of variation is how elite cultivars are developed, and by selecting superior individuals and then crossing them with other superior individuals, new pools of variation are created (Zamir, 2001).

Exotic Maize

By definition exotic maize germplasm is considered to be maize that is not adapted to target areas of maize production in the user's region (Holland, 2004). So in the U.S. exotic maize would be maize from other countries, both temperate and tropical, that is not adapted or commonly found in both the Corn Belt and other areas of U.S. maize production. Using exotic germplasm to improve existing elite maize germplasm is a difficult and laborious process, that requires long term efforts and appropriate breeding methodology, but can be accomplished (Goodman et al., 2000; Holland, 2004). It is commonly thought that the most diverse and readily useable exotic source of maize germplasm available to U.S. maize breeders is temperate and tropical maize from South America.

Two different methods of exotic germplasm usage have been proposed in the literature for maize and other crop species. The first, introgression, involves repeatedly backcrossing the exotic parent to the adapted parent the breeder seeks to improve, but results in very little of the exotic parent's genetic material being present in the final product (Holland, 2004; Simmonds, 1993). It is also easy to lose beneficial genes early in the process, and the genetic variation of the improved materials is only slightly changed. Introgression is valuable for transfer of major genes, many times resistance genes, into the adapted material, and can be made quicker by use of molecular markers. The other method of exotic germplasm utilization is incorporation, which involves development of populations that combine elite materials and the genetic diversity of the exotic germplasm (Holland, 2004; Simmonds, 1993). Several public maize breeding programs in the U.S. have been working to incorporate exotic maize germplasm into temperate maize using different breeding methods and different percentages of exotic maize germplasm (Goodman et al., 2000; Kraja et al., 2000; Lewis and Goodman, 2003; Tarter et al., 2003). For incorporation of exotic materials to be successful, the proportion of exotic germplasm must be high enough to broaden the genetic variation present in the materials to be improved and give reasonable opportunity to take advantage of novel alleles; yet too much exotic germplasm can affect the agronomic performance and adaptability of the improved maize (dos Santos et al., 2000; Lewis and Goodman, 2003).

Aflatoxin

Disease Information

Aflatoxin is a carcinogenic mycotoxin produced by the fungus *Aspergillus flavus* and is known to be toxigenic (Castegnaro and McGregor, 1998). The principal toxin produced by *Aspergillus flavus* is aflatoxin B_1, which is highly potent and widespread in food items, affecting as much as 25% of the world food crop (Moreno and Kang, 1999). Aflatoxins were one of the first mycotoxins to be classified, and were thought and later confirmed to be involved in human liver cancer (Castegnaro and McGregor, 1998). One of the problems that limits evaluation of maize germplasm for aflatoxin resistance is that natural infection can be sporadic from year to year (Windham and Williams, 2002). In addition to abiotic stresses, biotic stress such as insect feeding can also increase incidence of aflatoxin contamination of grain (Windham et al., 1999)

Importance of Aflatoxin

One of the major problems affecting maize production throughout the world is infection of kernels by toxigenic fungi that produce mycotoxins (Moreno and Kang, 1999; Munkvold, 2003). In countries where human diets are primarily made up of maize, there is the risk of toxic ingestion of aflatoxin. This has led to strict limits in aflatoxin contamination levels of maize grain for food and feed purposes as well as grain used in interstate and international commerce. In Texas and other southern U.S. areas of maize production, abiotic stresses (such as hot, dry climates) contribute to contamination of grain with aflatoxin.

Control Methods

Cultural practices, biocontrol of *Aspergillus flavus*, and management of storage conditions have been suggested and evaluated in order to reduce aflatoxin contamination of grain both pre- and post-harvest (Cleveland et al., 2003; Munkvold, 2003). Most of the agronomic practice strategy to reduce mycotoxin contamination is based on disease management principles, and includes altering tillage practices, soil fertility, crop rotation, plant populations, planting dates, and irrigation schedules (Munkvold, 2003). However, since *Aspergillus* overwinters in crop residue in the soil, tillage and rotation may not have much effect on aflatoxin contamination of grain. Biocontrol of aflatoxin using atoxigenic strains of *Aspergillus flavus* and *Aspergillus parisiticus* has been shown in several crops including maize, but cotton is the only crop for which there is a pesticide registration for use of atoxigenic fungi (Cleveland et al., 2003). If infection with *A. flavus* cannot be prevented preharvest, care must be taken with harvest timing, grain handling, and storage to prevent or slow continued development of toxins (Munkvold, 2003). Physical damage to grain must be prevented, and grain moisture must be reduced quickly to slow or prevent growth of *A. flavus*, but it is difficult to maintain optimal storage conditions for more than a short period of time (Munkvold, 2003).

While many methods have been proposed to reduce aflatoxin in maize grain and other crops, the best solution is genetic resistance (Munkvold, 2003). Currently there is a lack of resistant commercially available hybrids, but some resistance has been found in different populations and inbred lines developed by public breeding programs, but many resistant sources lack agronomic performance (Betrán et al., 2002; Campbell and White, 1995; Guo et al., 1995; Hamblin and White, 2000; Naidoo et al., 2002; Windham and Williams, 2002). Traits that might lend themselves to reduction of aflatoxin in maize include tight husk coverage, kernel hardness, silk volatiles, insect resistance, adaptation, and early maturity (Betrán et al., 2002; Munkvold, 2003; Warfield and Davis, 1996; Windham and Williams, 2002; Windham et al., 1999).

CHAPTER III

ARGENTINE HYBRIDS

Introduction

Argentine Maize

Most Argentine maize possesses denser grain with flinty, vitreous kernels and harder endosperm than that of traditional dent corns grown in the U.S., and this leads to heavier test weights with less susceptibility to breakage or damage (Paulsen and Hill, 1985; Robutti et al., 2000b). Orange grain color, tighter and longer husk coverage, and temperate adaptation are other important traits of Argentine maize that are desirable. Native landraces of Argentina could provide valuable breeding resources due to their genetic diversity, but these materials would need comprehensive assessment in order to be utilized properly in a U.S. breeding program (Robutti et al., 2000a). Material that would be more likely to make an instant impact on U.S. maize germplasm would have to be elite and agronomically adapted in order to facilitate introgression or incorporation.

Fortunately, Argentine maize grain yield has increased over the last 30 years, gain has been estimated to be 1.05 q ha^{-1} year^{-1} to 1.69 q ha^{-1} year^{-1} (Eyherabide and Damilano, 2001; Eyherabide et al., 1994). The rate of gain has been consistent, and it is similar to grain yield increases in other countries (Eyherabide and Damilano, 2001). Most of this gain may be due to abilities of new elite hybrids to benefit from better environmental conditions and agricultural inputs. Maize breeding programs in Argentina have been successful in developing new hybrids for both elite and suboptimal environments (Eyherabide and Damilano, 2001; Eyherabide et al., 1994). While crop management has changed in Argentina, so has the makeup of popular maize cultivars, as increased numbers of better performing single cross hybrids have been developed by companies after the 1990's (Eyherabide and Damilano, 2001). Elite Argentine hybrids might be suitable for use in U.S. breeding programs. However, before Argentine maize can be used for introgression or incorporation there is a need for characterization of elite materials and crosses in order to determine their worth to local U.S. breeding programs (Eyherabide and Gonzalez, 1997).

Kernel Characteristics

Kernel characteristics and quality are traits that are very important to maize processors and importers that often state Argentine maize is of superior quality (Paulsen and Hill, 1985). Kernel characteristics have also been used to classify maize into races such as dent, flint, floury, etc. (Robutti et al., 2000b). Harder kernels are less susceptible to damage at harvest and during shipping and handling (Dombrink-Kurtzman and Knutson, 1997).

Research in Canada has shown that Argentine maize germplasm represents novel variability for resistance to *Gibberella* and *Fusarium* ear rots (Presello et al., 2004). It is also possible that Argentine maize possesses novel alleles for resistance factors against aflatoxin contamination of grain. Kernel characteristics and integrity may play a role in aflatoxin resistance.

One of the objectives of this experiment was to compare Argentine hybrid grain traits, such as test weight and 1000 kernel weight, with U.S. hybrids. We also want to determine if test weight and 1000 kernel weight are correlated with grain yield, and if environment plays a role with those traits.

Materials and Methods

Materials

Fifteen commercial Argentine hybrids and five U.S. commercial hybrids were grown in eleven diverse Texas environments in 2004 (Table 1). Fourteen of the Argentine hybrids were temperate, with hybrid Agricom AGRI124 being a tropical hybrid. The U.S. hybrids are commonly grown in different Texas environments and across the southern U.S.

Table 1. List of Argentine and U.S. hybrids evaluated across Texas environments in 2004.

Company	Hybrid	Characteristics
Nidera	A933	106 DRM†, Three way cross
Nidera	AX877	NA‡
Nidera	AX878	NA
Nidera	AX882	100 DRM, Single cross
Nidera	AX884IT	Single cross, Clearfield
Nidera	AX888IT	Single cross, Clearfield
Nidera	AX889	Single cross
Nidera	AX934	104 DRM, Single cross
Nidera	AX956	NA
Nidera	AX882MG	Single cross, Bt
Nidera	AX890MG	Single cross, Bt
Monsanto	DK682	108 DRM, Single cross, orange grain
Syngenta	CONDOR	NA
Syngenta	NK900TDMAX	NA
Agricom	AGRI124	Early, Single cross, excellent aflatoxin resistance
Monsanto	DKC66-80	116 DRM
Monsanto	DKC69-70	119 DRM
Pioneer	P31B13	119 DRM
Pioneer	P32R25	116 DRM, exceptional drought tolerance
Warner	W4700	116 DRM

† Days to relative maturity.
‡ Not Available.

Field Evaluation

The environments ranged from subtropical to temperate, spanned ten degrees of latitude, and are representative samples of typical maize production environments in Texas. An alpha lattice design with incomplete blocks was used with either two or three replications per environment. Experimental units were two row plots everywhere but Weslaco, College Station, and Corpus Christi, where one row plots were used (Table 2).

Trials were planted in spring 2004 starting in February and ending in May depending on regular planting dates for each region. Agronomic and cultural practices were standard for the area where the evaluations were conducted.

Table 2. Test site information for Texas environments used in experiments.

Locations	Code	Latitude	Elevation (m)	Plot area (m^2/plot)	Water regime	2004 Planting Date
COLLEGE STATION, TX	CS	30°37'	96.0	9.95	Irrigated	Mar. 11
WESLACO, TX	WE	26°09'	22.5	5.08	Irrigated	Feb. 17
CORPUS CHRISTI, TX	CC	27°46'	12.9	8.16	Rainfed	Feb. 23
CASTROVILLE, TX	CA	29°21'	228.2	14.76	Irrigated	Mar. 24
BARDWELL, TX	BA	32°17'	126.4	12.37	Rainfed	Mar. 24
WHARTON, TX	WH	29°17'	30.3	16.38	Rainfed	Mar. 26
GRANGER, TX	GR	30°42'	172.4	15.60	Rainfed	Mar. 18
PROSPER, TX	PR	33°14'	194.2	12.14	Rainfed	Apr. 04
HALFWAY, TX†	HA	NA‡	1026.0	9.60	Irrigated	NA‡
DUMAS, TX†	DU	35°51'	1114.7	11.86	Irrigated	May 6
DALHART, TX†	DA	36°06'	1203.4	11.86	Irrigated	May 5

† Latitudes and elevations are estimates for these envirionments.
‡ Not Available.

Traits measured included plant and ear heights, lodging, flowering data, grain yield, test weights, moisture, and 1000 kernel weights. Plant height was taken at the end of growing season before harvest by measuring from the ground to the tip of the tassel, and ear height was taken from the ground to the base of the primary ear. Plant population was determined by counting the total number of plants per plot before harvest and converting to plants per hectare. Lodging was taken as both root lodging and stalk lodging and then combined and expressed as a percentage by combining number of plants root and stalk lodged then dividing by the total number of plants in a plot. Flowering data was taken by finding days to midsilk- the number of days from planting to the day when 50% of plants in a plot had silks showing- or days to anthesis- the number of days from planting to 50% of plants in a plot shedding pollen. Grain yield (adjusted to 15.5% grain moisture), grain moisture, and test weights were taken by mounted equipment in the combine during harvest. Five ear samples were taken from each entry in each replication at nine environments in order to determine test weights and 1000 kernel weights in the laboratory. The test weights reported here were taken in the lab.

Statistical Analysis

Single environment analysis of variance for grain moisture, grain yield, lodging, plant height, plant population, test weights, and 1000 kernel weights was conducted using Proc GLM in SAS 9.0 (SAS Institute, 2002). Contrasts were computed to compare the overall performance Argentine vs. U.S. hybrids for all traits using SAS. Data was analyzed using restricted maximum likelihood with the REMLTool© as both randomized complete block and alpha lattice with and without spatial analysis (Welen, 2003). The most efficient method with the lowest mean square error was used to estimate the adjusted means. Trait correlations were pictured using singular value decomposition (SVD) of hybrid by trait (previously standardized) table at each environment. Stability analysis was done with SVD (principal component analysis) of genotype by environment two-way table using the Biplot add-in in Microsoft Excel® and with linear regression of hybrid performance on environmental indices using SAS (Eberhart and Russell, 1966; Lipkovich and Smith, 2001).

Data was then combined across environments and overall means were determined using Proc Mixed in SAS 9.0 (SAS Institute, 2002). Overall means also were used to determine trait correlation using SVD.

Biplots are a useful way for plant breeders to interpret data from several environments in order to determine stability across environments, as well as relationships between environments, entries that are well suited to individual environments or clusters of environments, and even relationships between individual traits at single environments or across environments. Stability is important to maize breeders because elite hybrids need to show adaptation and superior yields in more than one environment in order to justify the expense of development. Hybrids need to perform well across environments and be able to respond to optimal environments and inputs.

Results

Single Environment Analysis

ANOVA and Means

Plant population is necessary to examine early in the analysis because of its impact on grain yield. No significant differences were detected between hybrids for plant population in individual environments, meaning that we can analyze grain yield without covariance analysis for plant population (Table 3). Replications were significant in Bardwell, but in other environments plant populations should be comparable between replications (Table 3).

Table 3. ANOVA table and repeatabilities for plant population (plants ha^{-1}) at Texas environments for Argentine and U.S. hybrids.

Source	df	Mean Square							
		CA†	BA	WH	GR	PR	DA	DU	WE‡
Reps	1	0.29	37.62*	7.83	4.54	34.37	3.48	42.66	1.15
Hybrids	19	21.74	7.31	5.83	14.29	23.50	30.30	41.79	25.04
Argentine	14	21.63	8.25	4.98	14.39	28.72	14.25	39.15	31.01
U.S.	4	9.63*	5.65	10.20	5.41	6.21	37.10	60.56	3.11
Argentine*U.S.	1	71.80	0.79	0.25	48.43*	19.67	227.87**	3.69	29.10
Error	19	18.75	5.62	7.44	7.86	17.74	14.98	25.75	20.01
Repeatability		0.14	0.23	0.00	0.45	0.25	0.51	0.38	0.20

* Significant at $P<0.05$
** Significant at $P<0.01$
† Location abbreviations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, DA=Dalhart, DU=Dumas, and WE=Weslaco.
‡ Due to another replication, Weslaco degrees of freedom for Reps=2 and Error=38.

For grain yield replications within environments were only significant in three environments, but due to fairly low error terms in most environments field variation for grain yield was not a problem, except for maybe Dalhart and Dumas (Table 4). Grain yield was significantly different ($P<0.05$) among hybrids in Bardwell, Wharton, Granger, Prosper, Halfway, Dalhart, College Station, and Corpus Christi (Table 4). In nine out of eleven environments significant differences ($P<0.05$) were seen between grain yield for U.S. hybrids and Argentine hybrids. Repeatabilities ranged from .40 to

.84, indicating that differences among hybrids were due mainly due to genotypic differences.

Table 4. ANOVA table and repeatabilities for grain yield (Mg ha^{-1}) at Texas environments for Argentine and U.S. hybrids.

Source	df	Mean Square								df	Mean Square		
		CA†	BA	WH	GR	PR	HA	DA	DU		CS‡	WE	CC
Reps	1	0.13	1.84*	0.69	0.04	1.20	1.15	0.61	7.16*	2	1.68	2.35*	0.63
Hybrids	19	1.78	1.13*	1.44**	0.93**	0.87**	3.77**	6.29*	2.65	19	2.73**	1.14	4.45**
Argentine	14	1.20	1.14*	1.72**	0.93**	0.96*	2.71*	6.06*	2.72	14	1.26**	0.62	1.94
U.S.	4	2.73	0.60	0.15	0.43	0.22	1.84	6.70	2.89	4	0.69	0.85	4.12*
Argentine*U.S.	1	6.24*	3.10*	2.60**	2.86**	2.23*	26.28**	7.94	0.81	1	29.45**	9.65**	40.84**
Error	19	1.07	0.42	0.22	0.17	0.39	0.89	2.51	1.38	38	0.57	0.64	1.10
Repeatability		0.40	0.63	0.84	0.82	0.55	0.76	0.60	0.48		0.79	0.44	0.75

* Significant at P<0.05
** Significant at P<0.01
† Location abbreviations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, HA=Halfway, DA=Dalhart, DU=Dumas, CS=College Station, WE=Weslaco, and CC=Corpus Christi.
‡ Due to missing entry, College Station degrees of freedom for Hybrids=18, U.S.=3, and Error=36.

Overall, grain yields were above average across Texas during the summer of 2004 due to plentiful rainfall and excellent growing conditions. Environments Dalhart, Halfway, and Dumas (the three high plains environments) had the highest environmental grain yield means and Wharton, Corpus Christi, and Prosper had the lowest environmental means (Table 5)(Figure 1). Statistical differences between Argentine and U.S. hybrids were detected in several environments, and in all environments U.S. hybrids had higher grain yield means than Argentine hybrids (Figure 1). Coefficients of variation values (CV) were all less than 15% (Table 5).

Table 5. Mean grain yields (Mg ha^{-1}) for Argentine and U.S. hybrids at each environment.

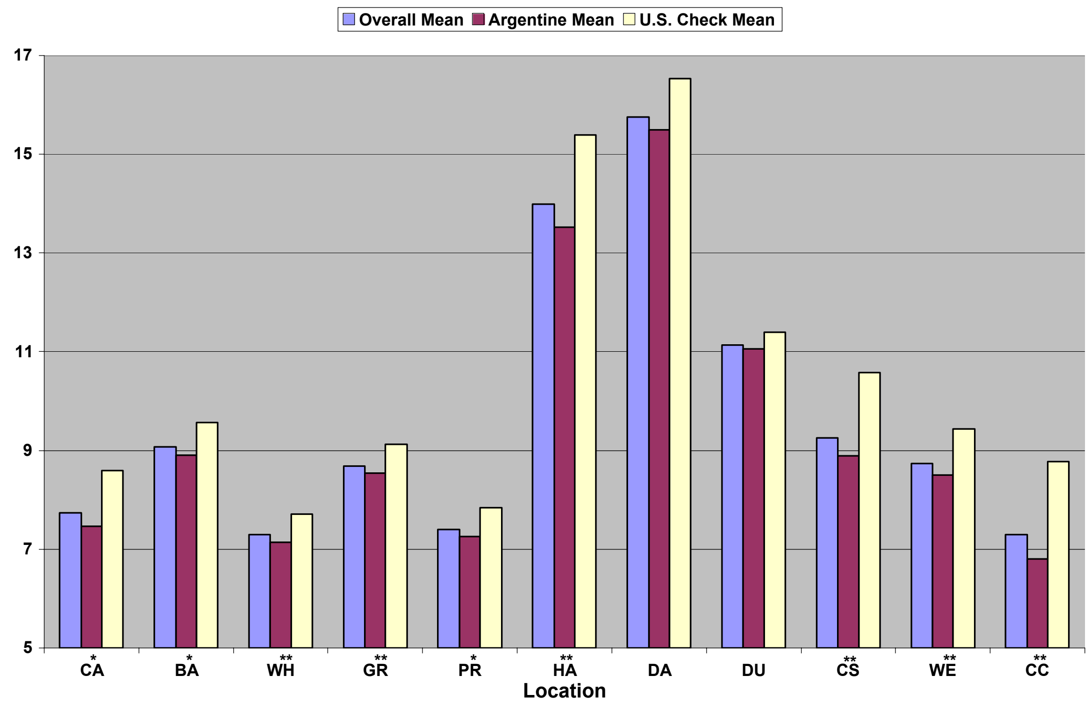
	Mg ha^{-1}										
	CA[†]	BA	WH	GR	PR	HA	DA	DU	CS	WE	CC
A933	6.95	8.53	7.37	8.61	6.54	11.19	14.68	11.02	8.96	8.40	6.20
AX877	7.24	8.76	7.06	6.87	6.51	13.04	17.17	11.03	7.66	8.92	7.33
AX878	8.10	9.40	8.17	8.97	8.51	14.57	14.02	11.80	8.91	8.31	6.67
AX882	7.22	8.94	7.31	7.78	6.66	13.62	16.21	11.97	8.16	8.53	6.01
AX884IT	6.41	7.71	7.57	8.34	7.37	12.54	15.25	11.07	8.38	7.56	6.22
AX888IT	8.94	9.11	7.69	8.71	6.80	14.56	13.79	9.28	8.97	8.86	6.68
AX889	7.58	9.00	7.01	8.81	7.91	14.48	17.76	10.96	9.67	8.81	8.43
AX934	7.08	8.45	7.02	9.59	6.41	13.71	15.49	13.11	9.19	8.56	6.65
AX956	7.22	9.69	7.19	9.37	7.25	11.42	16.38	9.69	9.68	8.38	7.29
AX882MG	8.15	9.25	7.90	8.75	7.71	14.17	17.38	12.72	9.14	9.39	7.59
AX890MG	7.68	10.49	6.44	8.91	7.83	15.34	15.77	10.67	9.72	8.63	8.15
DK682	7.93	9.02	7.83	8.98	7.72	13.86	15.11	10.84	9.25	8.94	7.01
CONDOR	6.46	8.45	6.74	8.54	7.24	13.38	17.02	11.44	8.78	7.95	6.19
NK900TDMAX	7.49	9.41	7.65	8.39	8.29	14.15	15.31	11.52	8.65	8.34	5.78
AGRI124	7.46	7.45	4.27	7.45	6.19	12.79	11.03	8.80	8.29	8.05	5.92
DKC66-80	10.42	8.93	8.03	9.45	8.15	14.22	16.79	10.55	10.46	9.73	8.00
DKC69-70	8.25	9.70	7.77	9.55	7.32	16.08	18.46	12.97	11.27	10.04	8.67
P31B13	8.17	10.29	7.67	9.17	8.04	15.90	17.91	12.40	9.90	8.84	10.18
P32R25	8.97	9.75	7.79	8.38	8.04	14.49	14.56	10.48	10.68	9.66	9.53
W4700	7.17	9.20	7.31	9.04	7.65	16.27	14.90	10.55	----	8.91	7.51
Overall Mean	7.74	9.08	7.29	8.68	7.41	13.99	15.75	11.14	9.25	8.74	7.30
LSD (0.05)[‡]	2.08	1.35*	0.98**	0.79**	1.25**	1.98**	3.30*	2.46	1.18**	1.36	1.76**
C.V., %	13.34	7.12	6.50	4.75	8.45	6.74	10.07	10.55	8.17	9.14	14.35

* Significant at P<0.05

** Significant at P<0.01

[†] Locations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, HA=Halfway, DA=Dalhart, DU=Dumas, CS=College Station, WE=Weslaco, and CC=Corpus Christi.

[‡] Fisher's least significant difference, use to compare individual hybrids.



* Significant difference between Argentine hybrids and U.S. hybrids at P<0.05
** Significant difference between Argentine hybrids and U.S. hybrids at P<0.01
CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, HA=Halfway, DA=Dalhart, DU=Dumas, CS=College Station, WE=Weslaco, CC=Corpus Christi.

Figure 1. Grain yield means for all hybrids, Argentine and U.S. hybrids across environments.

For test weight, replications within environments were only significant in two environments, but due to fairly low error terms in most environments field variation for test weight was not a problem, except for maybe Prosper (Table 6). Test weights were significantly different (P<0.05) among hybrids in Castroville, Bardwell, Wharton, Granger, Dalhart, College Station, Weslaco, and Corpus Christi. In only two out of nine environments, significant differences (P<0.05) were seen between test weights for U.S. hybrids and Argentine hybrids. Repeatabilities ranged from .51 to .95, indicating that differences among hybrids were mainly due to genotypic differences (Table 6).

Table 6. ANOVA table and repeatabilities for test weights (kg hl^{-1}) at Texas environments for Argentine and U.S. hybrids.

Source	df	Mean Square						df	Mean Square		
		CA†	BA	WH	GR	PR	DA		CS‡	WE	CC
Reps	1	3.04**	1.05	1.10	0.23	0.18	0.04	2	2.90	4.10*	0.76
Hybrids	19	6.70**	3.64*	5.88**	5.80**	4.68	3.56**	19	12.01**	6.06**	8.69**
Argentine	14	8.00**	4.43*	7.23**	6.48**	5.80	3.40**	14	14.41**	7.64**	11.43**
U.S.	4	3.08*	1.10	2.22	4.29*	1.92	0.28	4	0.28	4.48	1.24*
Argentine*U.S.	1	3.01	2.78	1.53	2.39*	0.10	18.84**	1	1.04	4.05	0.04
Error	19	1.11	1.40	0.73	0.51	2.28	0.84	38	1.07	1.22	0.46
Repeatability		0.83	0.61	0.88	0.91	0.51	0.76		0.91	0.80	0.95

* Significant at P<0.05
** Significant at P<0.01
† Location abbreviations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, DA=Dalhart, CS=College Station, WE=Weslaco, and CC=Corpus Christi.
‡ Due to missing entry, College Station degrees of freedom for Hybrids=18, U.S.=3, and Error=36.

Environments Dalhart and Granger had the highest environmental test weights, while environments Wharton and Prosper had the lowest test weights (Table 7)(Figure 2). While statistical differences (P<0.05) between Argentine and U.S. hybrids were only detected in Dalhart, in some environments the Argentine hybrids had higher test weights, and in others the U.S. hybrids had higher test weight (Figure 2). Coefficients of variation values were lower than 5% for all environments (Table 7).

Table 7. Test weight means (kg hl^{-1}) for each environment and for Argentine and U.S. hybrids.

	CA[†]	BA	WH	GR	PR	DA	CS	WE	CC
	kg hl^{-1}								
A933	78.90	76.45	75.83	78.50	76.02	81.56	77.91	77.84	76.89
AX877	74.89	74.38	71.90	74.15	72.04	75.73	70.93	71.61	73.17
AX878	73.07	74.15	71.18	74.40	72.84	77.17	74.31	73.21	73.83
AX882	73.01	74.72	74.06	75.40	74.56	78.27	73.88	73.57	72.88
AX884IT	75.82	75.44	73.49	74.90	74.22	77.95	75.11	74.48	73.96
AX888IT	77.05	77.42	76.74	78.40	75.72	79.24	78.67	76.30	78.16
AX889	75.63	75.14	75.63	78.00	76.98	78.10	76.42	75.06	76.33
AX934	76.35	74.34	75.58	77.41	75.38	78.88	77.10	76.87	76.29
AX956	78.00	75.38	74.68	78.91	74.30	78.89	77.47	75.99	76.54
AX882MG	74.33	75.44	73.80	75.28	73.36	78.22	74.12	73.85	74.19
AX890MG	75.04	74.35	75.30	76.89	74.58	78.11	76.92	75.39	77.03
DK682	78.79	77.84	76.29	78.90	75.91	79.43	76.98	75.78	74.12
CONDOR	78.70	77.62	76.21	78.43	77.27	76.81	76.76	76.36	76.33
NK900TDMAX	77.31	77.98	74.67	77.35	77.04	78.11	76.47	75.87	75.98
AGRI124	78.16	78.01	78.74	79.40	77.81	78.06	79.67	75.02	79.77
DKC66-80	76.89	75.81	74.60	76.15	75.21	77.17	76.18	75.09	75.55
DKC69-70	77.84	77.22	75.29	79.04	74.37	76.82	78.27	76.24	76.79
P31B13	76.33	76.89	74.41	76.42	76.98	76.42	75.45	76.26	75.89
P32R25	75.32	75.63	72.76	75.35	75.03	76.25	76.15	76.05	75.45
W4700	78.48	77.05	75.39	75.66	75.00	76.93	----	75.21	75.10
Overall Mean	76.49	76.06	74.82	76.95	75.23	77.90	76.25	75.30	75.71
LSD (0.05)[‡]	2.21**	2.48*	1.78**	1.49**	3.16	1.92**	1.71**	1.89**	1.12**
C.V.	1.38	1.56	1.14	0.92	2.01	1.18	1.35	1.47	0.89

* Significant at P<0.05

** Significant at P<0.01

[†] Locations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, DA=Dalhart, CS=College Station, WE=Weslaco, and CC=Corpus Christi.

[‡] Fisher's least significant difference, use to compare individual hybrids.

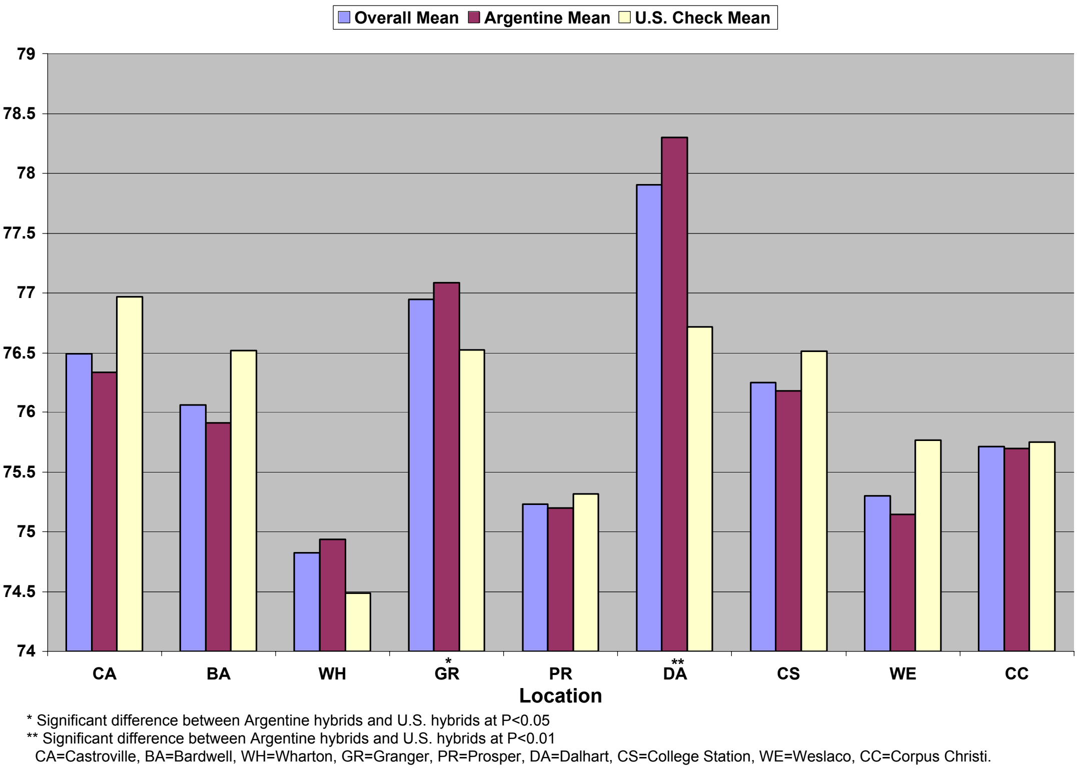


Figure 2. Test weight means for all hybrids, Argentine and U.S. hybrids across environments.

For 1000 kernel weight, replications within environments were only significant in one environment, but error terms in most environments except Dalhart and Weslaco indicated that field variation for 1000 kernel weight was not important (Table 8). One thousand kernel weights were significantly different ($P<0.05$) among hybrids in all environments except Weslaco. Significant differences ($P<0.05$) were seen between 1000 kernel weights for U.S. hybrids and Argentine hybrids in all environments except

Dalhart. Repeatabilities ranged from .44 to .96, indicating that differences among hybrids were due mainly due to genotypic differences (Table 8).

Table 8. ANOVA tables and repeatabilities for 1000 kernel weights (g) at Texas environments for Argentine and U.S. hybrids.

Source	df	Mean Square						df	Mean Square		
		CA[†]	BA	WH	GR	PR	DA		CS[‡]	WE[§]	CC
Reps	1	1363.06	36.10	19.60	14.40	0.40	819.03	2	1072.63	8224.93	4395.73**
Hybrids	19	1540.81**	2601.58**	1454.33**	1126.07**	1645.39**	2987.55**	19	2163.64**	2632.30	2962.74**
Argentine	14	1194.15*	1553.33**	879.71**	650.39*	1782.24**	3325.91**	14	1576.79**	2699.35	1885.78**
U.S.	4	769.69**	998.79*	104.96	2001.44*	482.69	1762.21	4	1314.69	198.67	407.14
Argentine*U.S.	1	9478.52**	23688.30**	14896.41**	4284.08**	4380.21**	3151.88	1	12926.28**	11078.83**	28262.67**
Error	19	317.48	190.13	120.64	222.11	321.29	752.75	38	426.50	1481.20	116.70
Repeatability		0.79	0.93	0.92	0.80	0.80	0.75		0.80	0.44	0.96

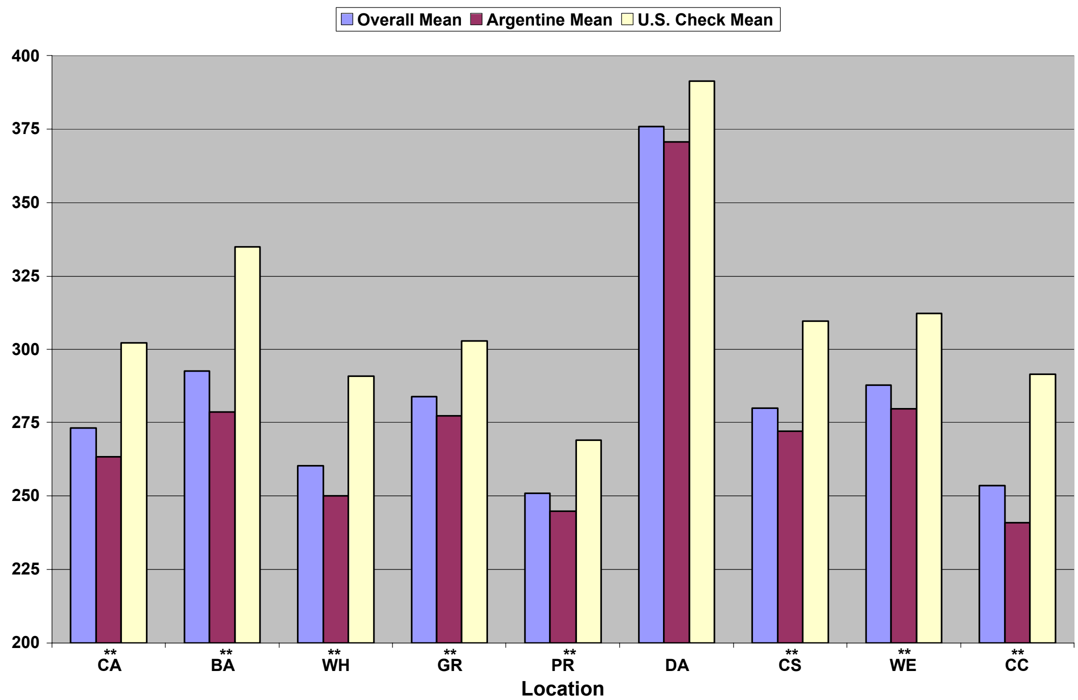
* Significant at P<0.05
** Significant at P<0.01
[†] Location abbreviations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, DA=Dalhart, CS=College Station, WE=Weslaco, and CC=Corpus Christi.
[‡] Due to missing entry, College Station degrees of freedom for Hybrids=18, U.S.=3, and Error=36.
[§] Due to missing plot, Weslaco degrees of freedom for Error=37.

For 1000 kernel weight, Dalhart had substantially higher environmental means and Corpus Christi and Prosper had the lowest environmental means almost 100 grams less than Dalhart (Table 9)(Figure 3). Significant differences were detected between the Argentine and U.S. hybrids in most environments, and as a group, the U.S. had a higher mean for 1000 kernel weights (Figure 3) Coefficients of variation values were all under 10% except for Weslaco where CV was 13.4% (Table 9).

Table 9. 1000 kernel weight means (g) for each environment and for Argentine and U.S. hybrids.

	---grams---								
	CA[†]	BA	WH	GR	PR	DA	CS	WE	CC
A933	247.29	222.47	222.29	250.87	222.00	310.54	240.15	257.50	219.26
AX877	261.67	283.96	264.24	260.00	225.75	344.21	257.97	240.83	242.78
AX878	237.55	269.91	232.47	249.33	224.50	325.62	267.87	265.83	226.72
AX882	250.55	303.98	257.56	277.53	250.75	408.76	256.02	310.00	270.60
AX884IT	289.21	287.83	279.97	288.29	253.75	442.11	283.64	297.50	248.58
AX888IT	271.49	302.14	284.03	283.70	250.50	406.81	297.14	247.50	275.47
AX889	299.48	294.31	283.16	307.70	295.00	424.78	300.60	308.33	266.24
AX934	244.81	226.81	236.34	291.10	224.00	335.59	280.83	260.83	229.95
AX956	238.62	252.07	218.23	269.31	189.00	343.14	247.86	260.00	233.58
AX882MG	249.87	297.79	244.89	265.33	250.25	393.06	249.54	272.50	245.28
AX890MG	266.81	294.75	241.47	271.94	242.75	409.86	281.96	325.00	251.87
DK682	282.86	288.80	271.24	305.62	249.50	337.19	277.26	294.17	207.39
CONDOR	247.48	253.64	239.35	267.50	227.75	341.59	261.41	247.50	207.67
NK900TDMAX	241.44	291.75	219.39	264.26	255.00	363.45	256.52	271.67	206.31
AGRI124	322.25	310.48	256.78	309.03	312.00	372.61	321.83	335.83	281.73
DKC66-80	306.59	296.06	287.61	283.46	284.75	379.14	302.86	302.50	288.49
DKC69-70	332.72	344.73	284.32	356.29	258.00	396.76	332.16	317.50	310.87
P31B13	296.07	340.23	299.41	297.26	254.00	414.29	282.40	310.00	286.18
P32R25	287.65	347.73	285.56	286.87	286.75	420.43	320.97	322.50	291.52
W4700	287.34	345.57	297.06	291.13	261.50	346.57	------	308.82	280.34
Overall Mean	273.09	292.75	260.27	283.83	250.88	375.82	279.95	287.82	253.54
LSD (0.05)[‡]	34.31**	28.82**	12.91**	29.70**	37.51**	57.37**	34.88**	66.62	18.40**
C.V.	6.52	4.71	4.22	5.25	7.14	7.30	7.38	13.40	4.26

* Significant at P<0.05
** Significant at P<0.01
[†] Locations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, DA=Dalhart, CS=College Station, WE=Weslaco, and CC=Corpus Christi.
[‡] Fisher's least significant difference, use to compare individual hybrids.



* Significant difference between Argentine hybrids and U.S. hybrids at P<0.05
** Significant difference between Argentine hybrids and U.S. hybrids at P<0.01
CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, DA=Dalhart, CS=College Station, WE=Weslaco, CC=Corpus Christi.

Figure 3. 1000 kernel weight means for all hybrids, Argentine and U.S. hybrids across environments.

For lodging, replications within environments were only significant ($P<0.05$) in one environment, Castroville (Table 10). Lodging was significantly different ($P<0.05$) among hybrids in Wharton and Granger, but significant differences ($P<0.05$) were not observed for lodging between U.S. hybrids and Argentine hybrids in any environment. Repeatabilities were variable and ranged from .00 to .81 (Table 10).

Table 10. ANOVA table and repeatabilities for plant lodging (%) at Texas environments for Argentine and U.S. hybrids.

Source	df	Mean Square						
		CA†	WH	GR	PR	DA	DU	WE‡
Reps	1	1665.52*	54.15	0.03	0.76	0.29	5.93	8.57
Hybrids	19	339.22	194.87**	1.30**	1.20	19.65	46.26	38.21
Argentine	14	416.61	225.49**	1.54**	1.47	14.30**	55.96	45.87
U.S.	4	118.82	135.63	0.73	0.25	40.73	5.15	7.74
Argentine*U.S.	1	137.41	3.17	0.15	1.21	10.29	74.96	52.94
Error	19	269.46	36.51	0.52	1.35	9.51	22.10	30.98
Repeatability		0.21	0.81	0.60	0.00	0.52	0.52	0.19

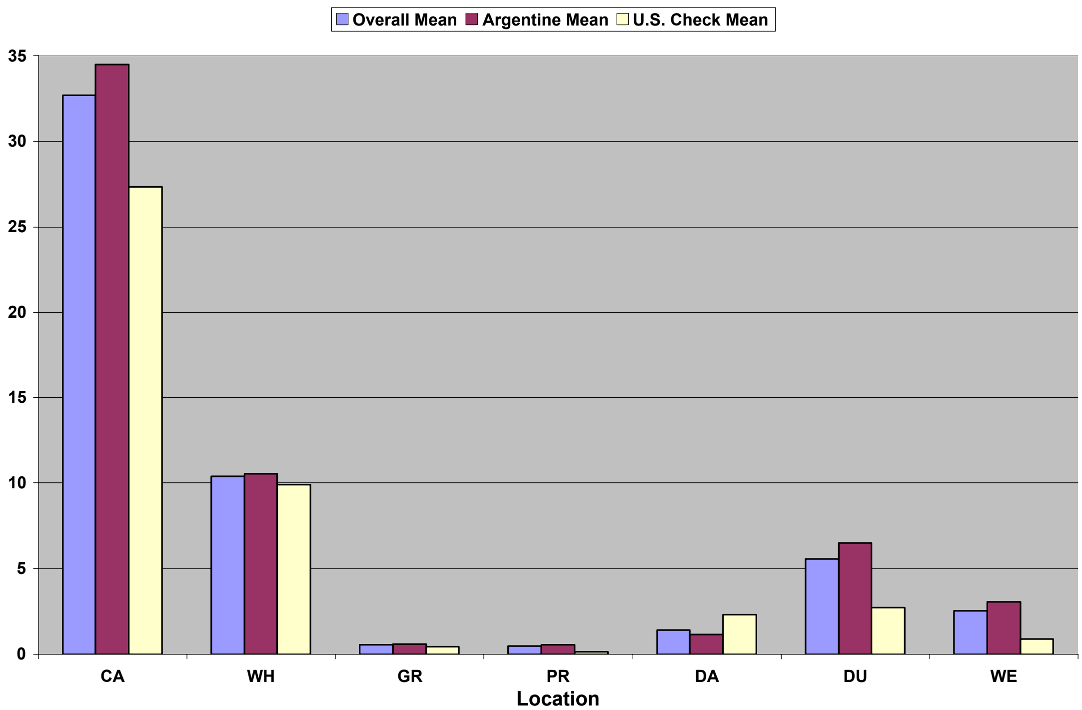
* Significant at P<0.05
** Significant at P<0.01
† Location abbreviations are CA=Castroville, WH=Wharton, GR=Granger, PR=Prosper, DA=Dalhart, DU=Dumas, and WE=Weslaco.
‡ Due to another replication, Weslaco degrees of freedom for Reps=2 and Error=38.

For lodging percentage, Castroville had substantially higher environmental means with 32.71% of plants being lodged, and Granger and Prosper had the lowest environmental means with less than 1% of plants lodged (Table 11) (Figure 4). While there was noticeable lodging in only a few environments, and statistical differences (P<0.05) were not detected, the Argentine hybrids as a group showed more lodging than the U.S. hybrids (Figure 4). Coefficients of variation values were high for all environments and ranged from 50.19% to 252.31%.

Table 11. Lodging means (%) for each environment and for Argentine and U.S. hybrids.

	---%						
	CA†	WH	GR	PR	DA	DU	WE
A933	31.78	2.41	0.00	0.00	0.00	8.71	0.68
AX877	10.63	23.87	1.27	0.00	0.00	3.02	0.00
AX878	28.55	3.29	2.43	0.00	0.00	5.63	2.84
AX882	33.32	2.86	0.00	0.03	0.00	5.69	6.61
AX884IT	34.11	3.83	0.00	0.03	1.28	4.44	0.00
AX888IT	35.15	2.98	0.00	0.76	0.64	5.15	1.48
AX889	67.79	25.95	0.00	1.64	1.83	6.54	12.51
AX934	44.70	5.69	0.00	2.40	0.00	4.21	0.00
AX956	30.81	9.03	0.56	0.60	0.63	22.81	2.50
AX882MG	36.16	1.46	0.55	0.03	0.00	4.77	3.62
AX890MG	57.75	31.25	1.65	0.74	2.09	4.71	10.37
DK682	16.09	4.82	2.24	0.00	0.00	5.84	3.72
CONDOR	36.23	18.85	0.00	0.04	0.00	4.95	0.00
NK900TDMAX	27.21	0.00	0.00	0.00	0.00	0.35	1.48
AGRI124	27.14	22.09	0.00	2.31	10.44	10.75	0.00
DKC66-80	19.02	3.19	1.03	0.00	0.59	2.33	0.72
DKC69-70	38.91	0.00	0.00	0.00	0.55	2.14	0.00
P31B13	35.03	19.46	1.17	0.77	0.00	0.53	0.00
P32R25	18.20	15.88	0.00	0.00	10.36	5.49	0.00
W4700	25.55	11.01	0.00	0.03	0.00	3.14	3.70
Overall Mean	32.71	10.39	0.54	0.47	1.42	5.56	2.51
LSD (0.05)‡	34.36	12.65**	1.51**	2.43	6.46	9.84	9.20
C.V., %	50.19	58.13	132.28	252.31	217.27	84.56	221.55

* Significant at P<0.05
** Significant at P<0.01
† Locations are CA=Castroville, WH=Wharton, GR=Granger, PR=Prosper, DA=Dalhart, DU=Dumas, WE=Weslaco.
‡ Fisher's least significant difference, use to compare individual hybrids.



* Significant difference between Argentine hybrids and U.S. hybrids at P<0.05
** Significant difference between Argentine hybrids and U.S. hybrids at P<0.01
CA=Castroville, WH=Wharton, GR=Granger, PR=Prosper, DA=Dalhart, DU=Dumas, WE=Weslaco.

Figure 4. Lodging percentage means for all hybrids, Argentine and U.S. hybrids across environments.

For plant height, replications within environments were not significant (P<0.05) in any of the environments (Table 12). Plant heights were significantly different (P<0.05) among hybrids in all environments, and significant differences between U.S. hybrids and Argentine hybrids were detected in all environments except Dumas. Repeatabilities were high and ranged from .77 to .92.

Table 12. ANOVA table and repeatabilities for plant height (cm) at Texas environments for Argentine and U.S. hybrids.

Source	df	Mean Square								
		CA†	BA	WH	GR	PR	HA	DA	DU	CS‡
Reps	1	10.32	4.03	2.58	2.58	52.26	67.60	78.06	64.52	88.06
Hybrids	19	476.71**	359.69**	247.54**	385.57**	502.17**	732.65**	795.72**	386.89**	446.29**
Argentine	14	426.94**	346.48**	98.56	258.74*	492.10**	647.55**	635.57**	454.75**	209.67*
U.S.	4	221.61	147.42	226.77	58.71	92.58	261.65*	701.61*	52.58	541.50**
Argentine*U.S.	1	2193.76**	1393.60**	2416.34**	3468.60**	2281.50**	3808.13**	3414.19**	774.19	3378.09**
Error	19	106.76	28.82	56.57	77.96	102.85	128.86	123.23	60.10	86.59
Repeatability		0.78	0.92	0.77	0.80	0.80	0.82	0.85	0.84	0.81

* Significant at P<0.05
** Significant at P<0.01
† Location abbreviations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, HA=Halfway, DA=Dalhart, DU=Dumas, and CS=College Station
‡ Due to another replication, College Station degrees of freedom for Reps=2 and Error=38.

Environments Bardwell and Prosper had the shortest plants, and Dalhart and Dumas had the tallest plants (Table 13) (Figure 5). The differences in plant height between Argentine and U.S. hybrids were significant (P<0.05) in most environments, with the Argentine hybrids being shorter than the U.S. hybrids (Figure 5). Coefficients of variation values were low (less than 5%) for all environments.

Table 13. Plant height means (cm) for each environment and for Argentine and U.S. hybrids.

	cm								
	CA†	BA	WH	GR	PR	HA	DA	DU	CS
A933	213.36	199.29	240.15	219.71	222.25	252.33	295.91	288.01	243.40
AX877	217.17	207.99	242.03	217.17	204.47	252.36	290.83	286.21	242.75
AX878	199.39	198.19	238.88	210.82	204.47	248.50	280.67	279.22	238.16
AX882	209.55	202.68	240.18	201.93	203.20	239.58	303.53	271.05	226.91
AX884IT	204.47	195.33	242.42	205.74	198.12	243.49	285.75	268.06	234.23
AX888IT	217.17	208.57	235.49	220.98	224.79	251.43	284.48	283.12	240.39
AX889	231.14	225.26	245.65	234.95	213.36	249.13	300.99	288.10	250.77
AX934	185.42	193.41	233.79	215.90	204.47	244.70	311.15	271.96	230.24
AX956	215.90	217.02	251.93	223.52	196.85	252.79	313.69	291.12	244.65
AX882MG	220.98	215.22	240.60	227.33	219.71	258.79	298.45	273.31	242.76
AX890MG	237.49	224.06	236.96	224.79	199.39	266.44	308.61	284.84	248.77
DK682	209.55	198.09	239.33	200.66	193.04	236.86	269.24	259.52	225.15
CONDOR	222.25	213.65	243.07	229.87	212.09	250.63	314.96	284.39	247.05
NK900TDMAX	226.06	211.46	240.14	231.14	219.71	260.00	297.18	291.55	246.51
AGRI124	242.57	240.58	262.74	236.22	255.27	303.09	344.17	323.04	255.20
DKC66-80	217.17	220.08	251.35	242.57	236.22	280.08	299.72	290.12	251.92
DKC69-70	234.95	223.01	257.97	236.22	224.79	260.13	336.55	298.81	248.99
P31B13	236.22	226.81	260.24	243.84	222.25	256.73	326.39	286.29	237.79
P32R25	234.95	237.09	275.32	248.92	236.22	283.23	340.36	296.73	263.75
W4700	246.38	213.21	249.39	236.22	224.79	275.73	303.53	289.39	275.20
Overall Mean	221.11	213.55	246.38	225.43	215.77	258.30	305.31	285.24	244.73
LSD (0.05)‡	21.62**	11.06**	15.11**	18.48**	21.22**	16.34**	23.23**	15.83**	13.83**
C.V., %	4.67	2.51	3.05	3.92	4.70	4.39	3.64	2.72	3.80

* Significant at P<0.05
** Significant at P<0.01
† Locations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, HA=Halfway, DA=Dalhart, DU=Dumas, CS=College Station.
‡ Fisher's least significant difference, use to compare individual hybrids.

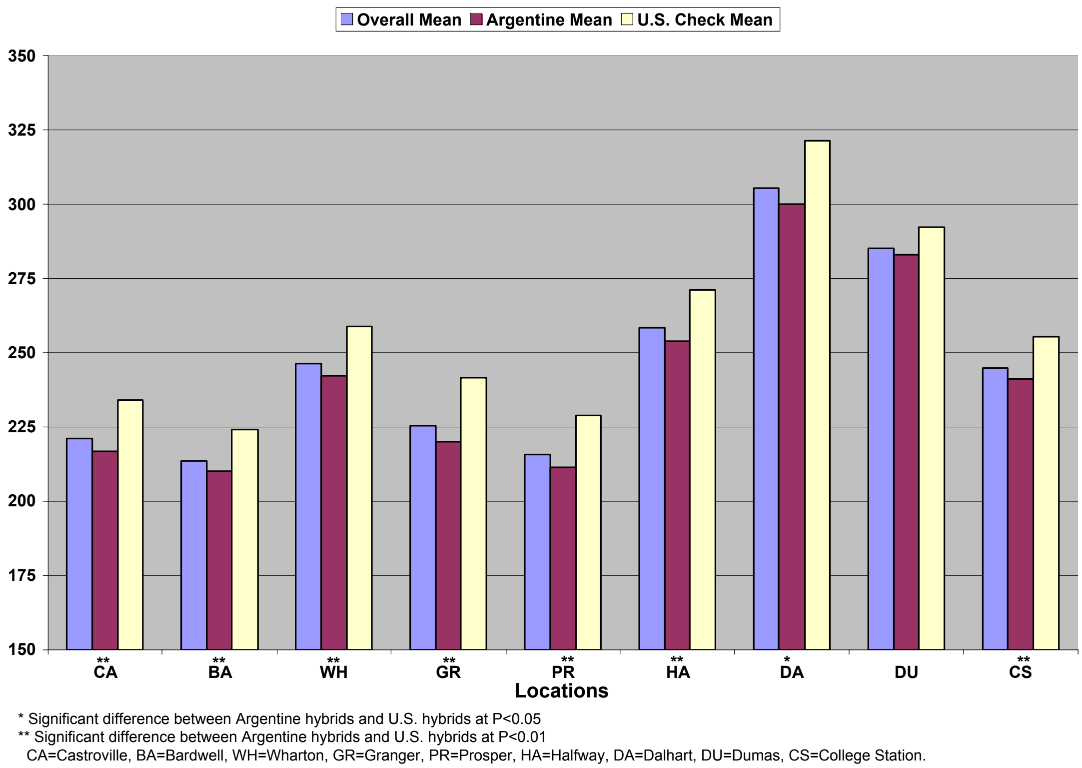


Figure 5. Plant height means for all hybrids, Argentine and U.S. hybrids across environments.

For grain moisture, replications within environments were only significant (P<0.05) in Halfway (Table 14). Grain moisture was significantly different (P<0.05) among hybrids in all environments except for Prosper, and significant differences between U.S. hybrids and Argentine hybrids were detected in Wharton, Halfway, Dalhart, and Dumas. Repeatabilities were high and ranged from .54 to .98.

Table 14. ANOVA table and repeatabilities for grain moisture (%) at Texas environments for Argentine and U.S. hybrids.

Source	df	Mean Square								
		CA†	BA	WH	GR	PR	HA	DA	DU	WE‡
Reps	1	0.93	0.04	0.18	0.04	0.20	25.86*	2.45	1.44	1.92
Hybrids	19	3.23**	0.79**	3.13**	7.27**	5.34	40.94**	20.63**	18.06**	3.55**
Argentine	14	4.19**	0.78**	3.81**	7.90**	6.08*	33.49**	12.63**	15.63**	3.95**
U.S.	4	0.44	1.00*	0.87	6.11**	2.78	10.41	4.68	3.06*	2.92
Argentine*U.S.	1	0.95	0.02	2.73*	3.04**	5.13	267.25**	196.35**	112.13**	0.62
Error	19	0.36	0.12	0.48	0.14	2.47	3.98	2.25	1.21	0.98
Repeatability		0.89	0.85	0.85	0.98	0.54	0.90	0.89	0.93	0.72

* Significant at P<0.05

** Significant at P<0.01

† Location abbreviations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, HA=Halfway, DA=Dalhart, DU=Dumas, and WE=Weslaco.

‡ Due to another replication, Weslaco degrees of freedom for Reps=2 and Error=38.

Environments Halfway, Dalhart, and Dumas had the highest grain moisture, and Castroville and Bardwell had the lowest grain moisture (Table 15) (Figure 6). Differences between Argentine hybrids and U.S. hybrids were significant (P<0.05) in several environments. In general, Argentine hybrids had greater grain moisture than U.S. hybrids (Figure 6). Coefficients of variation values were low for all environments (less than 10%) except Prosper.

Table 15. Grain moisture means (%) for different environments and for Argentine and U.S. hybrids.

	%								
	CA[†]	BA	WH	GR	PR	HA	DA	DU	WE
A933	13.40	12.15	12.73	14.01	13.85	26.55	25.99	24.86	15.94
AX877	10.70	11.28	10.56	10.04	10.80	20.80	24.52	19.05	13.71
AX878	10.65	11.36	10.91	10.68	11.85	28.65	23.59	22.04	13.22
AX882	12.15	11.75	11.55	11.07	12.45	23.55	23.25	21.96	14.04
AX884IT	11.50	11.49	11.20	11.42	12.15	28.10	21.27	21.47	13.66
AX888IT	12.10	11.78	12.04	12.70	12.35	19.75	22.33	17.59	13.72
AX889	11.45	11.67	12.21	12.40	13.35	19.50	22.35	20.04	14.11
AX934	11.75	11.75	12.75	13.69	15.25	28.50	27.41	27.06	17.21
AX956	12.20	12.07	11.86	14.00	12.15	24.65	26.85	24.22	14.63
AX882MG	10.90	11.59	11.54	11.08	12.15	22.30	23.73	22.16	14.23
AX890MG	11.50	11.76	11.97	12.40	11.70	24.25	23.75	19.75	14.59
DK682	11.80	11.89	11.49	11.94	11.85	18.40	19.17	19.15	13.37
CONDOR	11.85	12.38	13.04	12.99	14.65	26.30	26.76	23.50	15.01
NK900TDMAX	12.25	13.08	13.52	11.82	14.90	33.25	28.02	25.16	15.09
AGRI124	16.65	13.44	16.42	17.94	17.30	24.20	26.40	26.02	13.16
DKC66-80	11.25	11.85	11.46	11.32	11.80	17.55	19.53	16.47	12.88
DKC69-70	12.50	12.98	12.51	15.07	12.00	21.95	21.40	19.25	15.44
P31B13	11.55	11.45	12.23	11.02	14.35	17.17	19.24	19.35	13.74
P32R25	11.60	11.26	11.14	10.89	11.95	16.45	17.13	19.20	13.99
W4700	11.60	12.02	11.63	11.28	11.35	19.95	19.07	17.82	14.60
Overall Mean	11.97	11.95	12.14	12.39	12.91	23.09	23.09	21.31	14.32
LSD (0.05)[‡]	1.25**	0.71**	0.00**	0.69**	3.29	4.18**	3.13**	2.29**	1.67**
C.V., %	5.00	2.91	5.69	3.07	12.17	8.64	6.50	5.15	6.92

* Significant at P<0.05

** Significant at P<0.01

[†] Locations are CA=Castroville, BA=Bardwell, WH=Wharton, GR=Granger, PR=Prosper, HA=Halfway, DA=Dalhart, DU=Dumas, WE=Weslaco.

[‡] Fisher's least significant difference, use to compare individual hybrids.

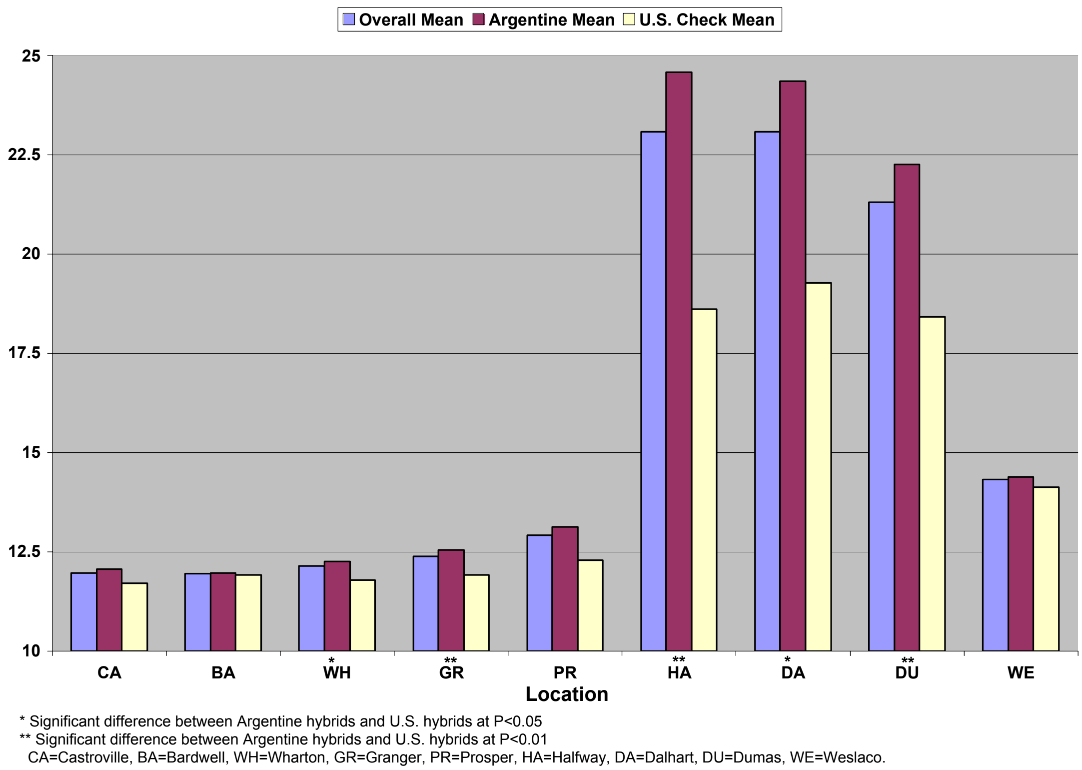
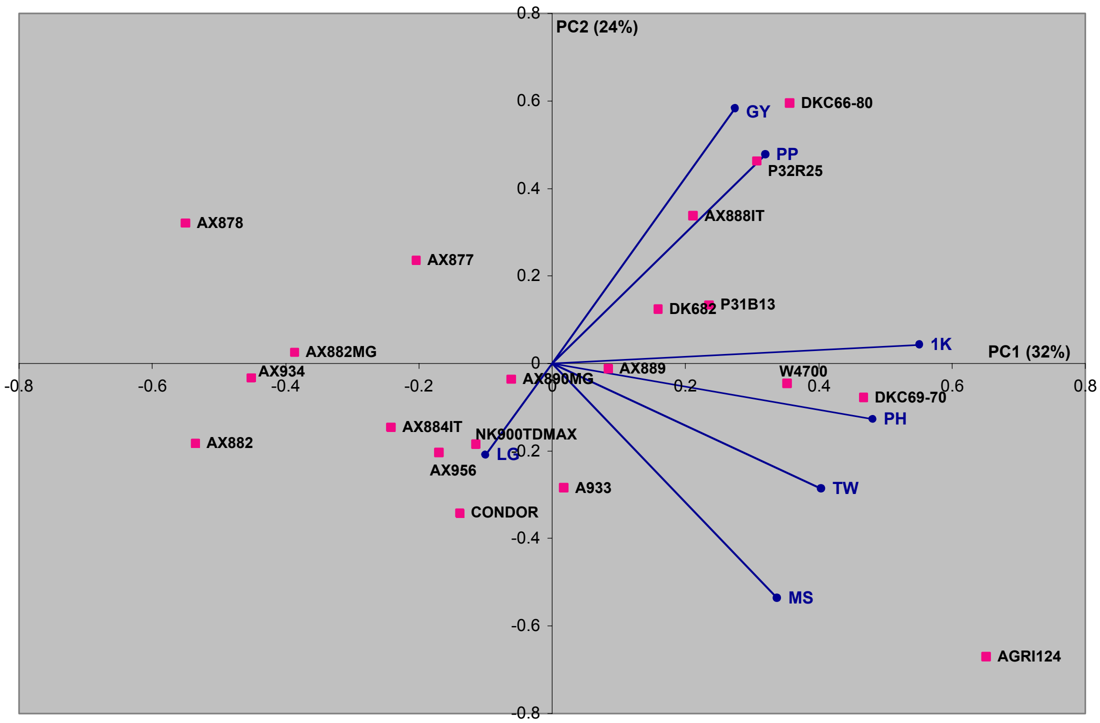


Figure 6. Grain moisture means for all hybrids, Argentine and U.S. hybrids across environments.

Relationship Among Traits

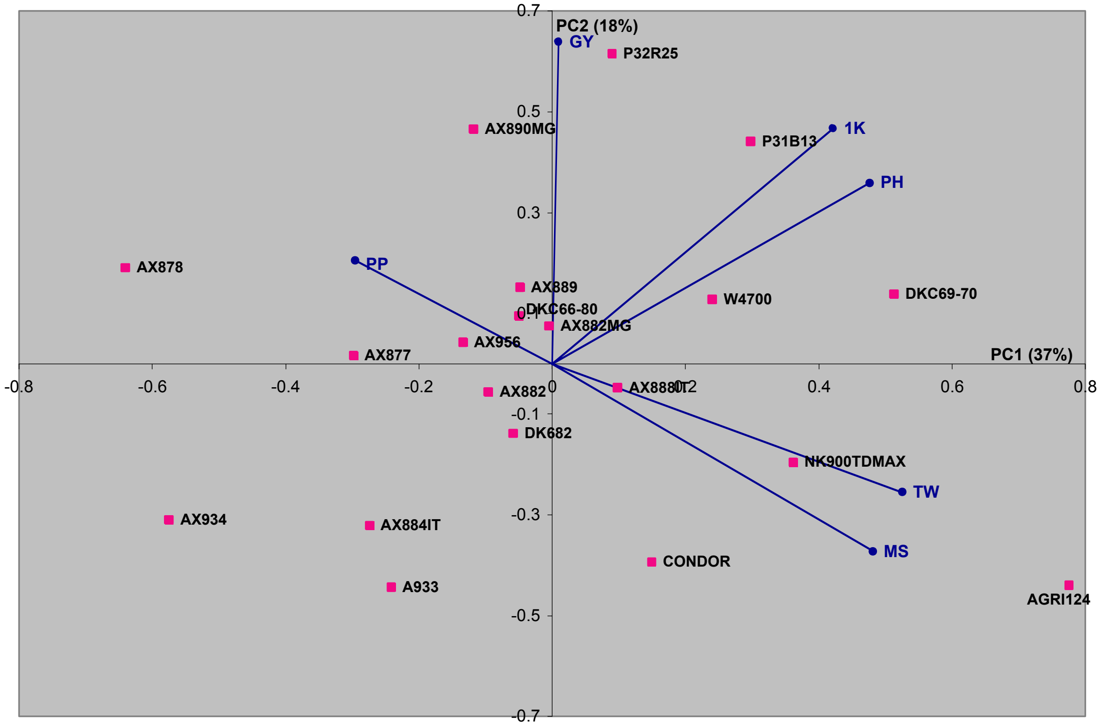
Singular value decomposition biplots were used to illustrate trait correlations in individual environments. In Castroville the first two principal components explained 56% of the variation among traits (Figure 7). Traits that showed positive correlation with grain yield were plant population and 1000 kernel weight. Grain moisture, test weight, plant height and 1000 kernel weight were also positively correlated. Hybrids DKC66-80, P32R25, and AX888IT, which were the top yielding hybrids in Castroville, had the highest projection on the grain yield vector (Figure 7) (Table 5).



GY=grain yield, PP=plant population, 1K=1000 kernel weights, PH=plant height, TW=test weight, MS=moisture, LD=lodging.

Figure 7. Singular value decomposition biplot of hybrid by trait for Argentine and U.S. hybrids at Castroville, Texas.

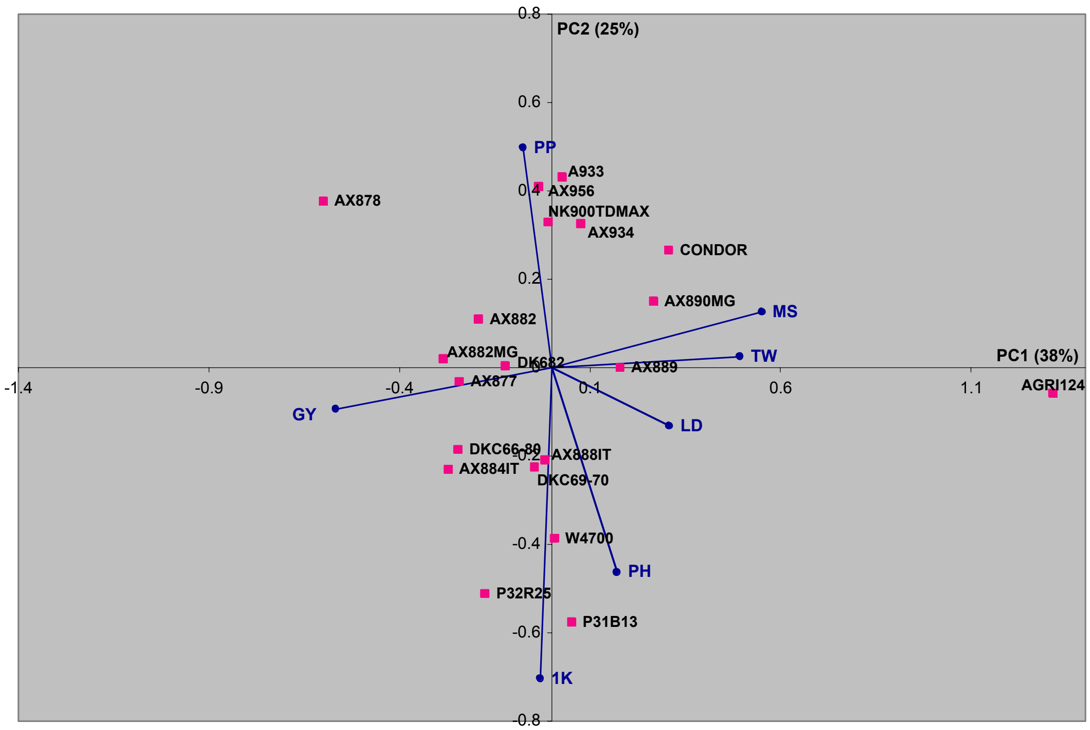
In Bardwell, the SVD biplot explained 65% of the variation (Figure 8). Plant population and 1000 kernel weight showed positive correlation with grain yield, as did plant height. Test weight and grain moisture were also positively correlated, with hybrids AGRI124 and NK900TDMAX showing high values for these traits (Figure 8) (Table 7). Hybrids P32R25, P31B13, and AX890MG had the highest yields and some of the highest 1000 kernel weights in Bardwell (Figure 8) (Table 5).



PP=plant population, GY=grain yield, 1K=1000 kernel weights, PH=plant height, TW=test weight, MS=moisture.

Figure 8. Singular value decomposition biplot of hybrid by trait for Argentine and U.S. hybrids at Bardwell, Texas.

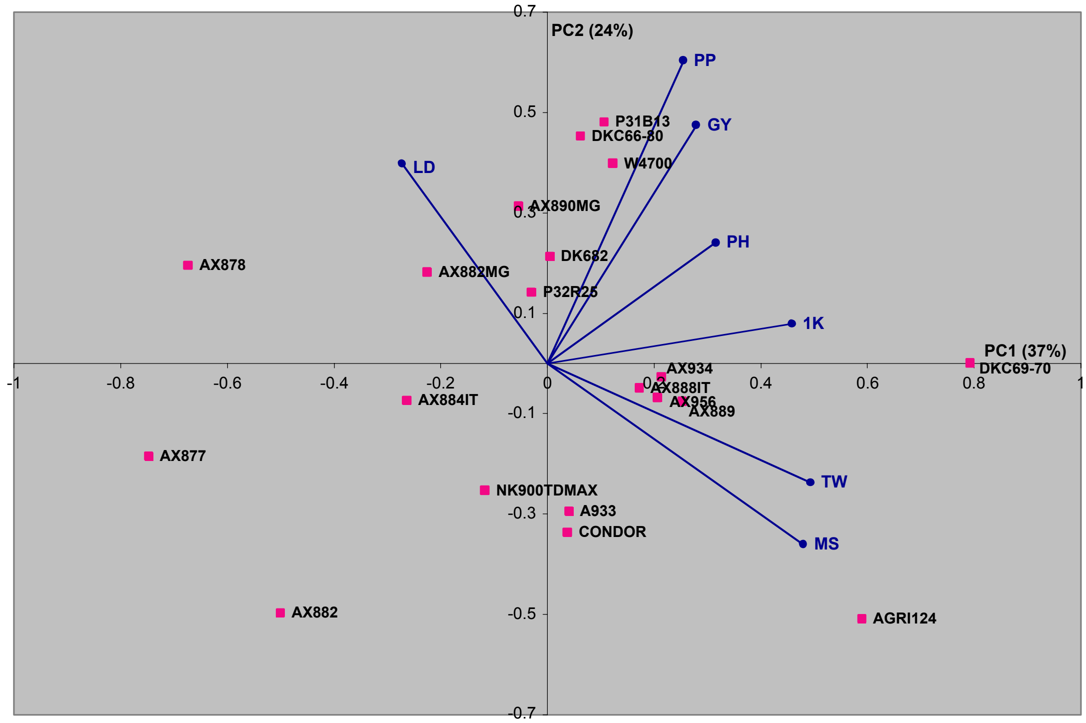
In Wharton, SVD biplot explained 63% of variation. The only trait that seemed to have positive correlation with grain yield was 1000 kernel weight. One thousand kernel weight was positively correlated with plant height and lodging, and lodging with test weight and grain moisture (Figure 9). Hybrids AX878, DKC66-80, AX882MG, and P32R25 had the highest grain yields in Wharton (Figure 9) (Table 5).



GY=grain yield, PP=plant population, MS=moisture, TW=test weight, LD=lodging, PH=plant height, 1K=1000 kernel weights.

Figure 9. Singular value decomposition biplot of hybrid by trait for Argentine and U.S. hybrids at Wharton, Texas.

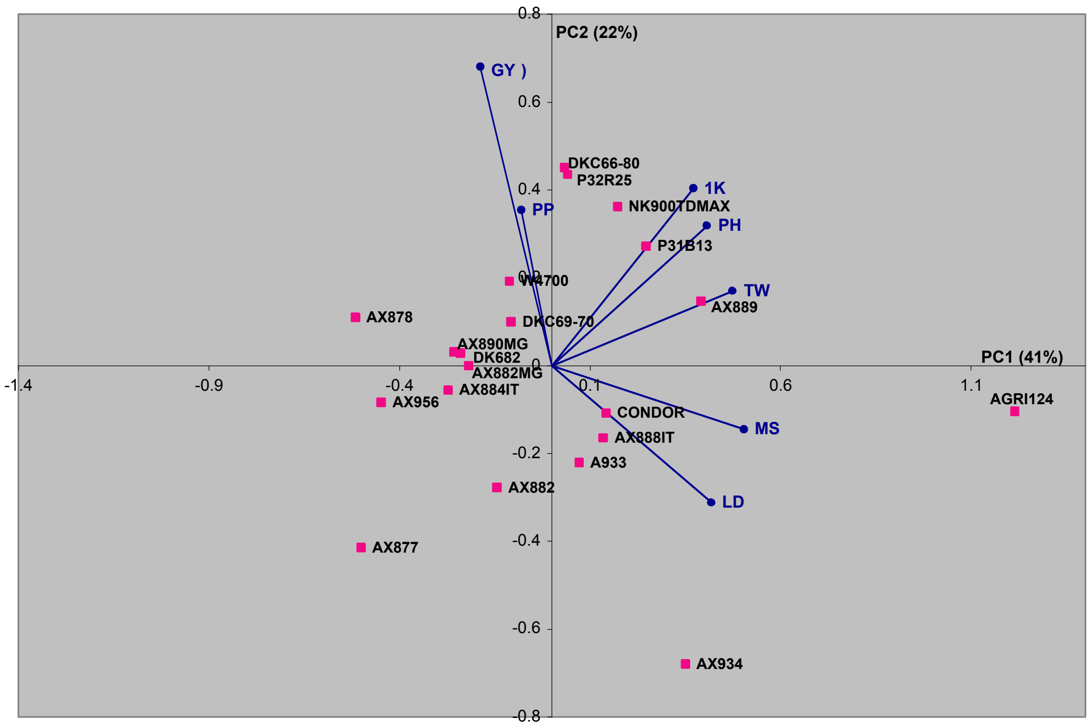
In Granger, SVD biplot explained 61% of the variation. Grain yield appeared positively correlated with plant population, plant height, and 1000 kernel weight. Test weight, grain moisture, and 1000 kernel weight were also positively correlated (Figure 10). Hybrids P31B13, DKC66-80, W4700, AX934, and AX956 are the highest yielding hybrids in Granger, with AX934 also having a fairly high 1000 kernel weight mean (Figure 10) (Table 5)(Table 9).



LD=lodging, PP=plant population, GY=grain yield, PH=plant height, 1K=1000 kernel weights, TW=test weight, MS=moisture.

Figure 10. Singular value decomposition biplot for hybrid by trait for Argentine and U.S. hybrids at Granger, Texas.

In Prosper, SVD biplot explained 63% of the variation. Grain yield was positively correlated with plant population, 1000 kernel weight, plant height, and possibly test weight (Figure 11). Test weight, grain moisture, and lodging were positively correlated. Hybrids DKC66-80, P32R25, P31B13, AX878, and NK900TDMAX were the highest yielding entries in Prosper, with P31B13 and NK900TDMAX also having high test weight means (Figure 11) (Table 5)(Table 7).



GY=grain yield, PP=plant population, 1K=1000 kernel weights,, PH=plant height, TW=test weight, MS=moisture, LD=lodging.

Figure 11. Singular value decomposition biplot for hybrid by trait for Argentine and U.S. hybrids at Prosper, Texas.

In Halfway, SVD biplot explained 77% of the variation. Grain yield showed positive relationship with plant population, and negative correlation with grain moisture (Figure 12). Hybrids W4700, DKC69-70, P31B13, and AX890MG were the highest yielding entries in Halfway (Figure 12) (Table 5).

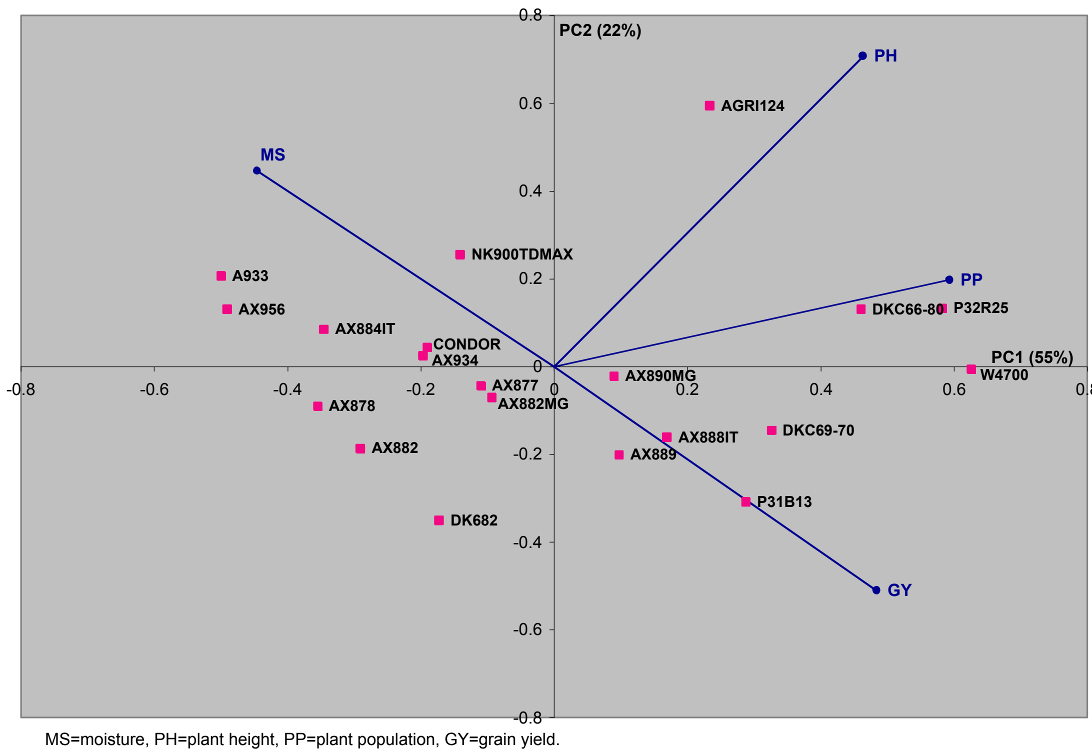


Figure 12. Singular value decomposition biplot for hybrid by trait for Argentine and U.S. hybrids at Halfway, Texas.

In Dalhart, SVD biplot explained 60% of the variation. Grain yield showed positive relationship with both plant population and 1000 kernel weight, and negative correlation with test weight and grain moisture (Figure 13). In addition lodging, plant height, and 1000 kernel weight were positively correlated as well as grain moisture and test weight. Hybrids DKC69-70, P31B13, AX882MG, AX889, AX877, and CONDOR were the highest yielding entries in Dalhart (Figure 13) (Table 5).

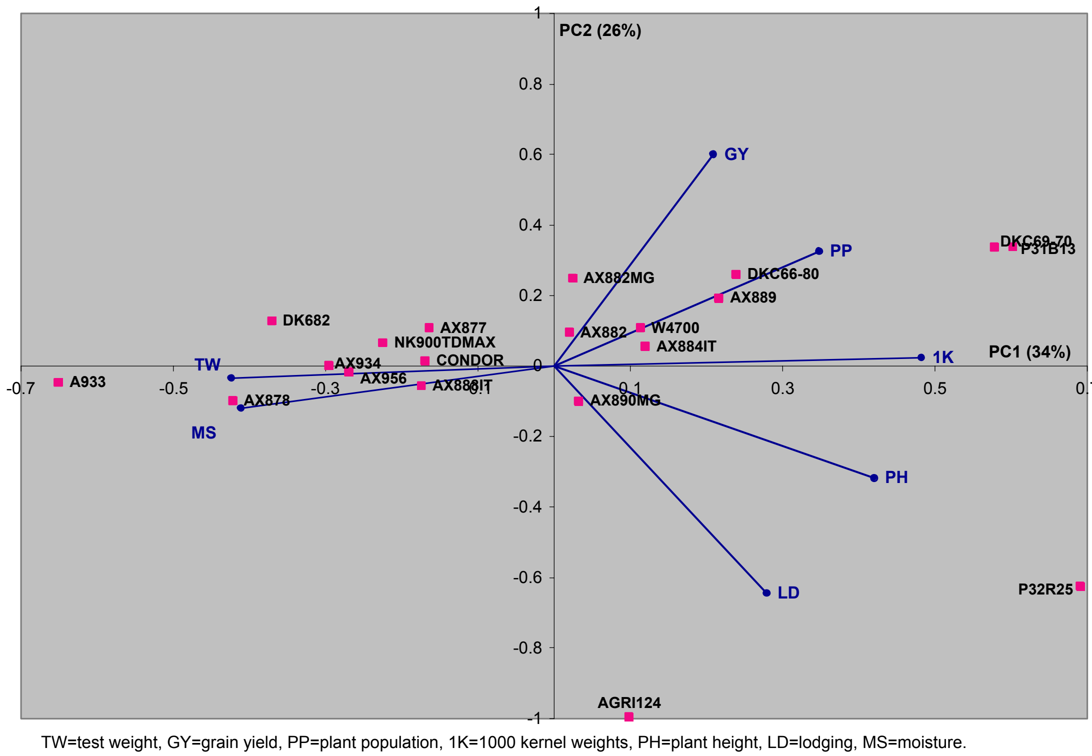
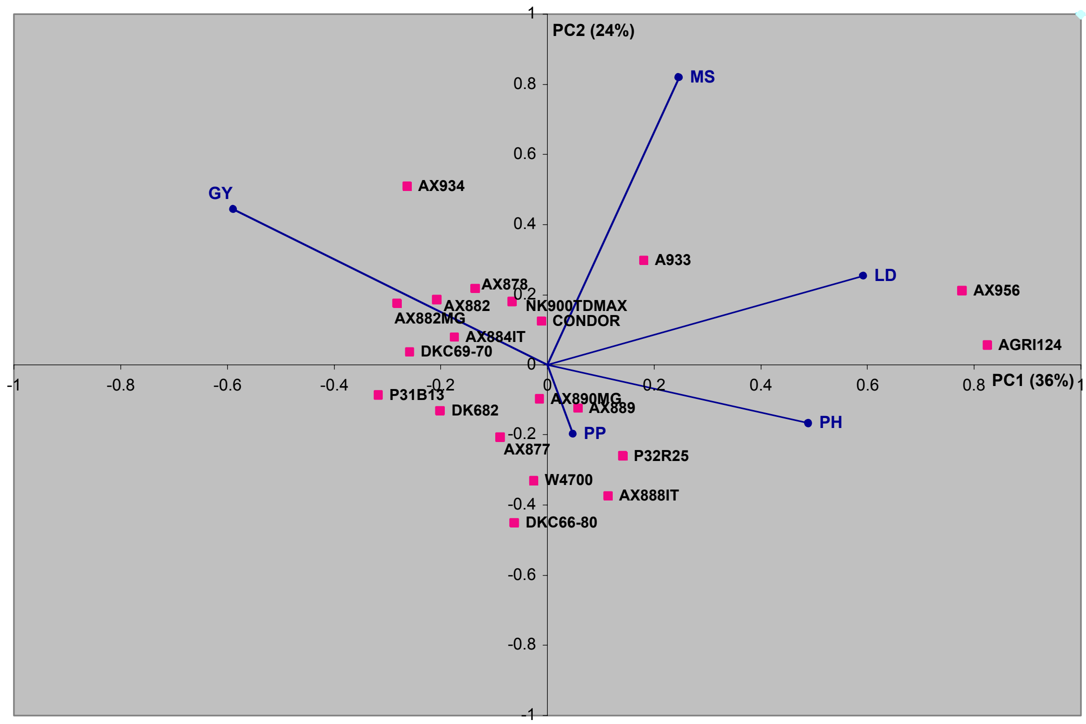


Figure 13. Singular value decomposition biplot for hybrid by trait for Argentine and U.S. hybrids at Dalhart, Texas.

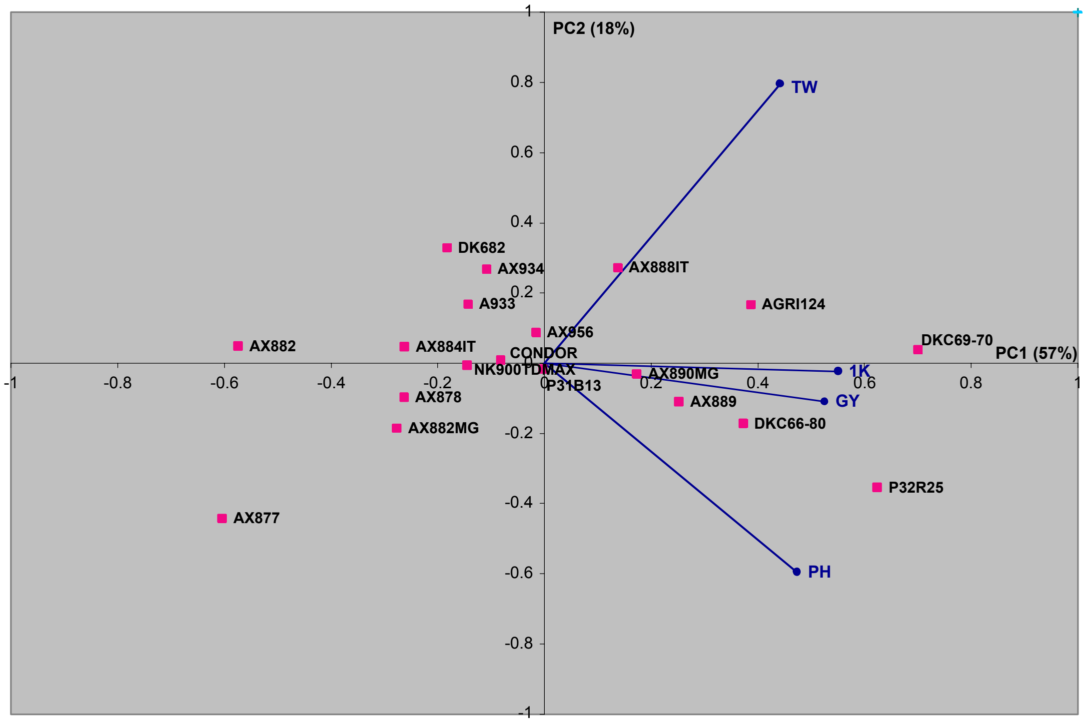
In Dumas, SVD biplot explained 60% of the variation. Grain yield was negatively correlated to lodging and plant height. Plant population, plant height, and lodging were positively correlated, as well as moisture and lodging (Figure 14). Hybrids AX934, DKC69-70, AX882MG, and P31B13 were the top yielding entries in Dumas (Figure 14) (Table 5).



GY=grain yield, MS=moisture, LD=lodging, PH=plant height, PP=plant population.

Figure 14. Singular value decomposition biplot for hybrid by trait for Argentine and U.S. hybrids at Dumas, Texas.

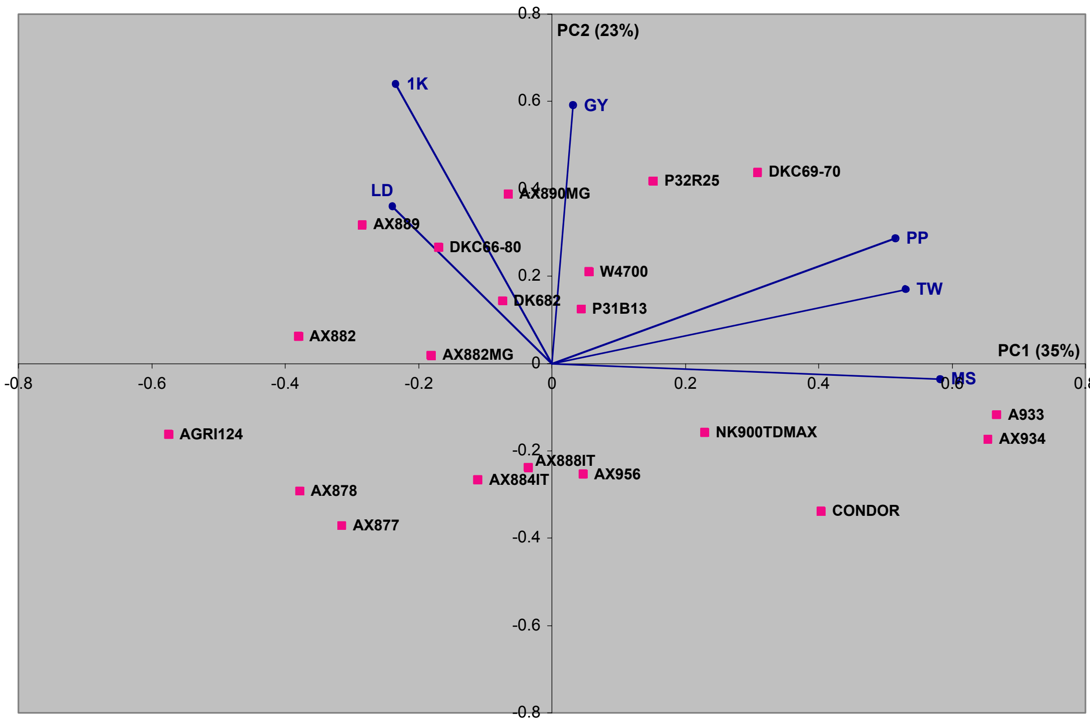
In College Station, SVD biplot explained 75% of the variation. Grain yield appears strongly correlated with 1000 kernel weight, and moderately correlated to both plant height and test weight (Figure 15). Hybrids DKC69-70, P32R25, and DKC66-80 were the highest yielding entries in College Station, and no Argentine hybrid yielded higher than the U.S. hybrids. Hybrids AX890MG and AX889 were top yielding Argentine hybrids in College Station (Figure 15) (Table 5).



TW=test weight, 1K=1000 kernel weights, GY=grain yield, PH=plant height.

Figure 15. Singular value decomposition biplot for hybrid by trait for Argentine and U.S. hybrids at College Station, Texas.

In Weslaco, SVD biplot explained 58% of the variation. Grain yield appeared related to two groups, one with lodging and 1000 kernel weight and the other with plant population, test weight, and grain moisture (Figure 16). Hybrids DKC69-70, DKC66-80, AX882MG, and P32R25 were the highest yielding entries in Weslaco (Figure 16) (Table 5).



LD=lodging, 1K=1000 kernel weights, GY=grain yield, PP=plant population, TW=test weight, MS=moisture.

Figure 16. Singular value decomposition biplot for hybrid by trait for Argentine and U.S. hybrids at Weslaco, Texas.

In Corpus Christi, SVD biplot explained 88% of the variation. Grain yield was correlated to 1000 kernel weight (Figure 17). Highest yielding hybrids for Corpus Christi were P31B13, P32R25, DKC69-70, AX889, and AX890MG (Figure 17) (Table 5).

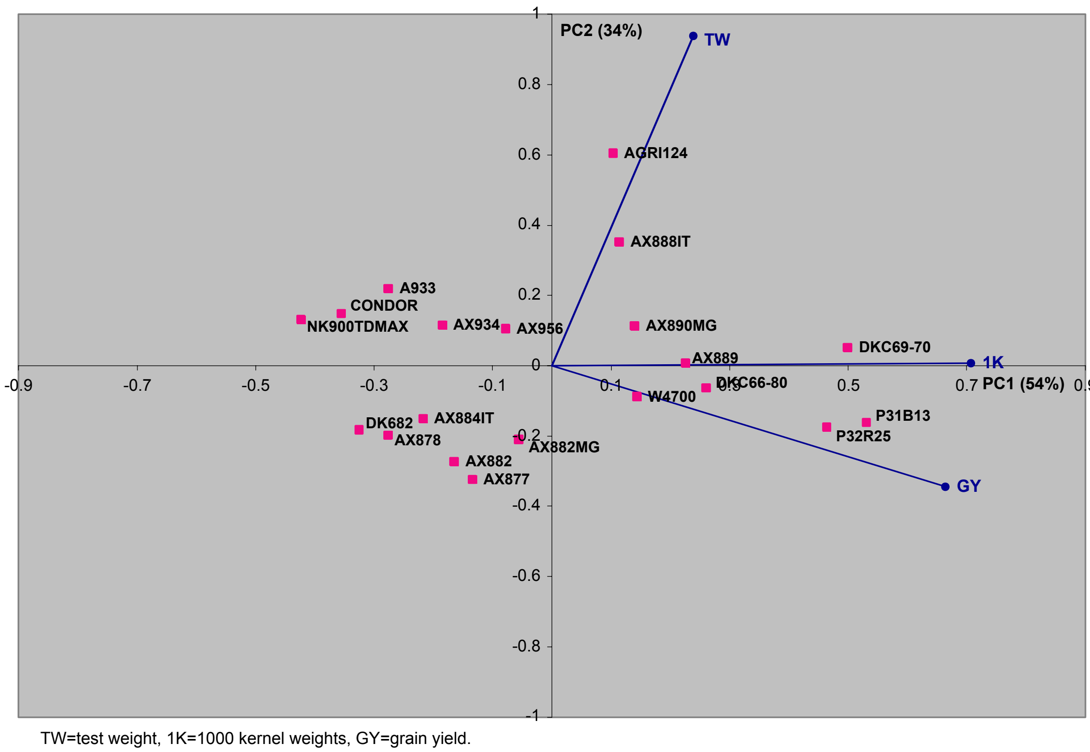


Figure 17. Singular value decomposition biplot for hybrid by trait for Argentine and U.S. hybrids at Corpus Christi, Texas.

Relationships between individual traits changed between individual environments, as did relationships between hybrids and traits. Top yielding hybrids in the southern environments were not the same as the top yielding hybrids in northern environments. In most environments, however, both plant population and 1000 kernel weight appeared positively correlated with grain yield, and grain moisture appeared correlated with test weight.

Across Environment Analysis

ANOVA and Means

Analysis of variance across environments showed significant differences among environments for all traits (Table 16). Significant differences among hybrids across environments were found for all traits, and all traits except test weight and lodging showed significant differences between Argentine and U.S. hybrids. There was also significant interaction between environments and hybrids for all traits except plant population. Repeatabilities were high and ranged from .79 to .99.

Table 16. ANOVA table and repeatabilities for grain yield (Mg ha^{-1}), test weights (kg hl^{-1}), 1000 kernel weights (g), plant population (plants ha^{-1}), plant height (cm), lodging (%), and moisture (%) across all environments for Argentine and U.S. hybrids.

Source	df	Mean Square	df	Mean Square		df	Mean Square	df	Mean Square	df	Mean Square	df	Mean Square
		Grain Yield		Test Weight	1000 Kernel Weight		Plant Population		Plant Height		Lodging		Grain Moisture
Env	10	333.14**	8	38.28**	58503.52**	7	1355.74**	9	38855.79**	6	5463.49**	8	1013.49**
Reps(Env)	14	1.58*	12	1.76	2469.93**	9	14.79	10	45.81	8	217.98**	10	3.50**
Hybrids	19	11.19**	19	35.54**	12355.49**	19	40.41**	19	3032.71**	19	158.09**	19	48.92**
Argentine	14	7.28**	14	46.43**	9292.88**	14	34.14*	14	2446.60**	14	199.13**	14	42.91**
U.S.	4	4.80**	4	6.34**	1887.06*	4	13.08	4	537.46**	4	27.88	4	14.65**
Argentine*U.S.	1	100.59**	1	0.14	93134.90**	1	237.50**	1	21219.30**	1	104.34	1	270.04**
Env*Hybrid	189	1.54**	151	2.30**	771.95**	133	18.27	171	149.32**	114	80.71**	152	7.07**
Env*Argentine	140	1.42**	112	2.37**	753.75**	98	18.02	126	138.50**	84	94.02**	112	5.94**
Env*U.S.	39	1.67*	31	1.54	731.82	28	17.80	36	197.61*	24	47.42	32	2.19
Env.*Argentine*U.S.	10	2.65**	8	4.37**	1182.25*	7	23.53	9	107.64	6	27.55	8	42.32**
Error	264	0.84	225	1.03	494.03	171	15.35	190	85.83	152	50.18	190	1.30
Repeatability		0.96		0.79	0.98		0.83		0.99		0.84		0.97

* Significant at P<0.05.
** Significant at P<0.01.

Overall means for grain yield, test weight, 1000 kernel weight, plant population, lodging, and grain moisture are presented in Table 17. U.S. hybrids had a higher mean grain yield (10.44 Mg ha^{-1}) than the Argentine hybrids (9.41 Mg ha^{-1}), and four of the U.S. hybrids (DKC69-70, P31B13, DKC66-80, and P32R25) were the top performers overall for grain yield. Hybrids AX882MG, AX889, and AX890MG were the highest yielding Argentine hybrids across environments (Table 17).

Table 17. Means for grain yield (Mg ha^{-1}), test weight (kg hl^{-1}), 1000 kernel weights (g), plant population (plants ha^{-1}), lodging (%), and grain moisture (%) across all environments for Argentine and U.S. hybrids.

	Grain Yield	Test Weight	Kernel Weight	Plant Population	Lodging	Plant Height	Moisture
A933	8.94	77.78	245.23	60.19	5.90	238.97	17.74
AX877	9.22	73.11	263.74	58.93	5.49	238.15	14.61
AX878	9.72	73.77	256.82	58.18	6.22	230.34	15.85
AX882	9.23	74.46	287.58	56.62	6.95	229.49	15.75
AX884IT	8.92	75.02	295.24	59.63	6.24	226.98	15.81
AX888IT	9.44	77.53	289.85	59.70	6.58	237.62	14.99
AX889	10.06	76.38	306.92	60.93	16.72	244.99	15.21
AX934	9.53	76.52	260.11	61.16	8.00	229.22	18.37
AX956	9.46	76.66	250.73	61.67	9.20	241.19	16.99
AX882MG	10.19	74.70	274.99	59.47	6.48	239.23	15.53
AX890MG	9.99	76.04	287.08	60.38	15.24	245.25	15.76
DK682	9.70	77.03	278.33	61.53	4.41	221.32	14.30
CONDOR	9.24	77.12	253.68	59.31	8.49	243.69	17.39
NK900TDMAX	9.51	76.76	262.07	60.37	4.23	244.00	18.55
AGRI124	8.05	78.30	315.08	57.42	10.23	269.79	19.05
DKC66-80	10.44	75.85	304.82	62.83	4.46	252.04	13.82
DKC69-70	10.92	76.94	327.57	60.38	6.12	254.28	15.91
P31B13	10.81	76.17	307.61	61.80	7.86	252.09	14.43
P32R25	10.23	75.38	315.83	61.74	7.41	264.60	13.69
W4700	9.80	76.06	302.02	61.42	6.71	254.54	14.37
Overall Mean	9.67	76.08	284.27	60.18	7.65	242.89	15.91
Argentine Mean	9.41	76.08	275.16	59.70	8.02	238.68	16.39
U.S. Mean	10.44	76.08	311.57	61.63	6.51	255.51	14.44
LSD (0.05)†	0.54**	1.00**	13.16**	2.32**	5.48**	4.19**	0.67**
C.V., %	9.60	1.33	7.86	6.52	96.86	3.79	7.2

* Significant at P<0.05
** Significant at P<0.01
† Fisher's least significant difference, use to compare individual hybrids.

For test weight, U.S. hybrids and Argentine hybrids had the same overall mean, but Argentine hybrids showed greater variation in test weights (73.11 to 78.30 kg hl^{-1})

than U.S. hybrids (75.34 to 76.98 kg hl^{-1}). Argentine hybrids AGRI124, A933, AX888IT, CONDOR, and DK682 had the highest test weights, and were greater than the test weights of all U.S. hybrids. The lowest means for test weight were also Argentine hybrids though, as AX877, AX878, and AX882 had the lowest values for test weight (Table 17). U.S. hybrids had a higher mean 1000 kernel weight than Argentine hybrids. The five U.S. hybrids along with AX889 and AGRI124 had the highest 1000 kernel weights, and A933, AX956, CONDOR, and AX878 had the lowest 1000 kernel weights (Table 17).

U.S. hybrids also performed slightly better for lodging percentage, but other than hybrids AX889, AX890MG, and AGRI124 most of the hybrids performed similarly and had lodging less than 10%. Argentine hybrids had lower overall plant heights than the U.S. checks, but also more variability. Argentine hybrids also had higher grain moisture percentages at harvest than the U.S. hybrids, although Argentine hybrids DK682, AX877, and AX888IT had grain moisture similar to U.S. hybrids. Coefficients of variation were under 10% for all traits except for lodging percentage, which was quite high but comparable with single environment analysis (Table 17).

Relationship Among Traits

Single value decomposition of hybrid by trait illustrated the correlations between the different yield components such as test weight, 1000 kernel weight, grain yield and other agronomic traits across environments (Figure 18).

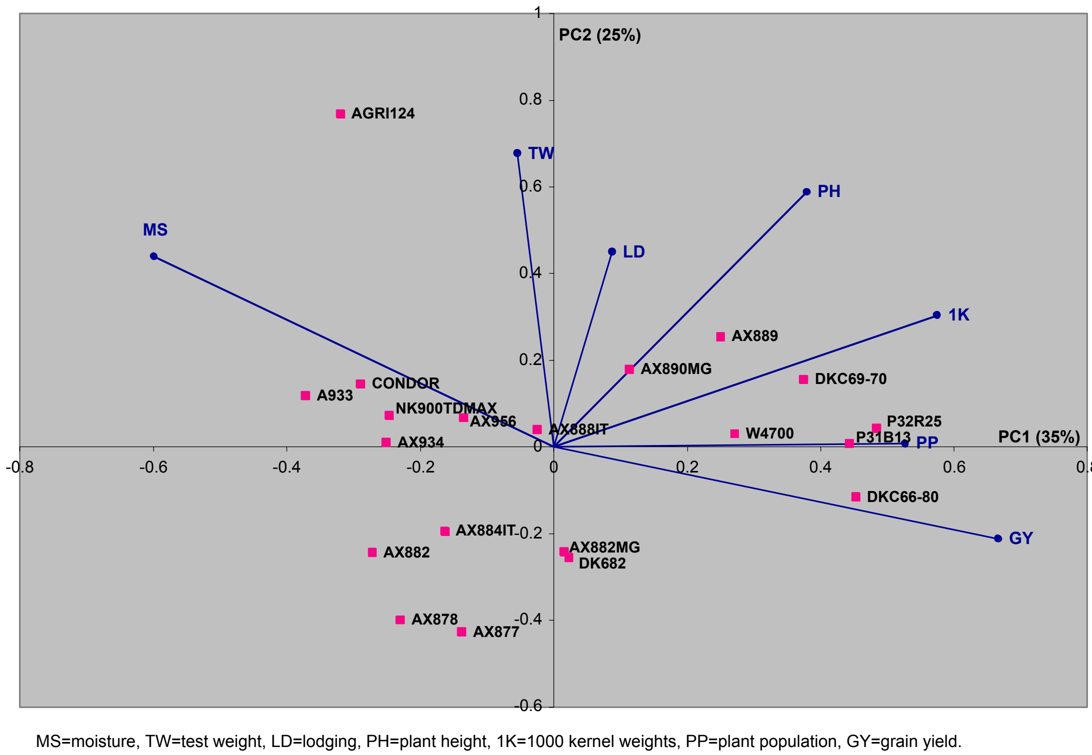


Figure 18. Singular value decomposition biplot of hybrid by trait across all environments for Argentine and U.S. hybrids.

Grain yield was negatively correlated with test weight and grain moisture when overall means across environments are used in SVD. However, when single environmental means for grain yield and test weight were plotted against each other, Dalhart had distinguishable high grain yield and test weight means values (Figure 19).

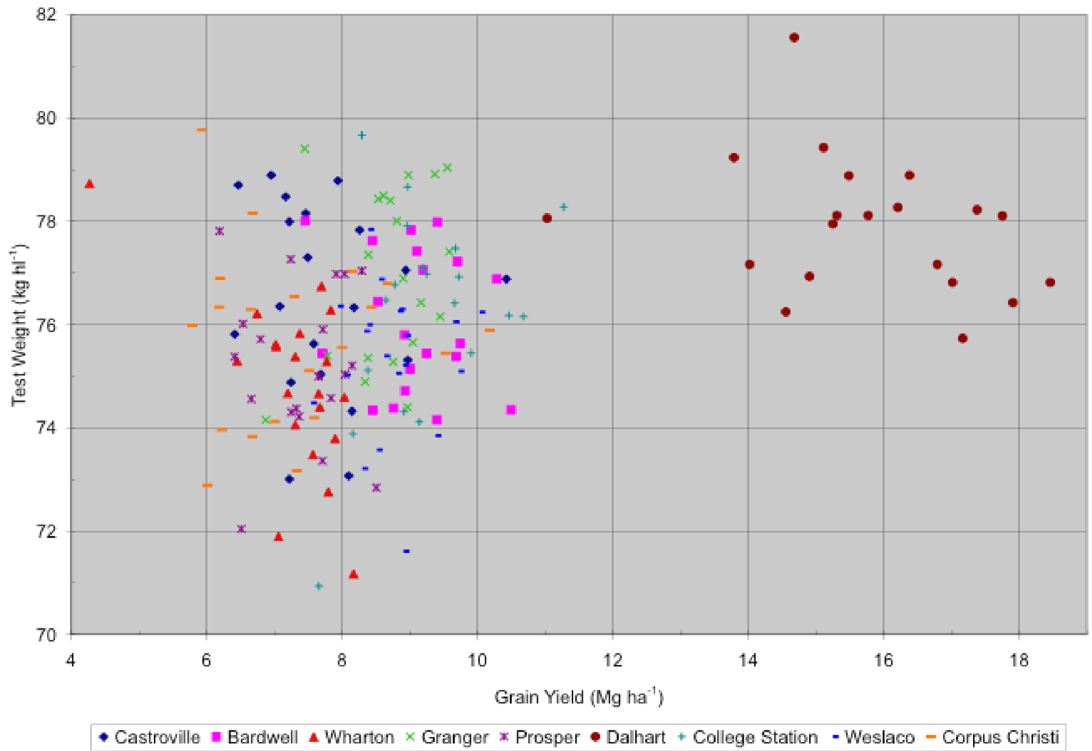


Figure 19. Test weight means vs. grain yield means at different environments in Texas for Argentine and U.S. hybrids.

Grain yield and 1000 kernel weight appeared positively correlated, as when 1000 kernel weight increases across environments the grain yield also increases (Figure 20). Again Dalhart stands out from the other environments with higher 1000 kernel weights and grain yields, and the other environments are clustered fairly tightly with lower grain yield and 1000 kernel weights.

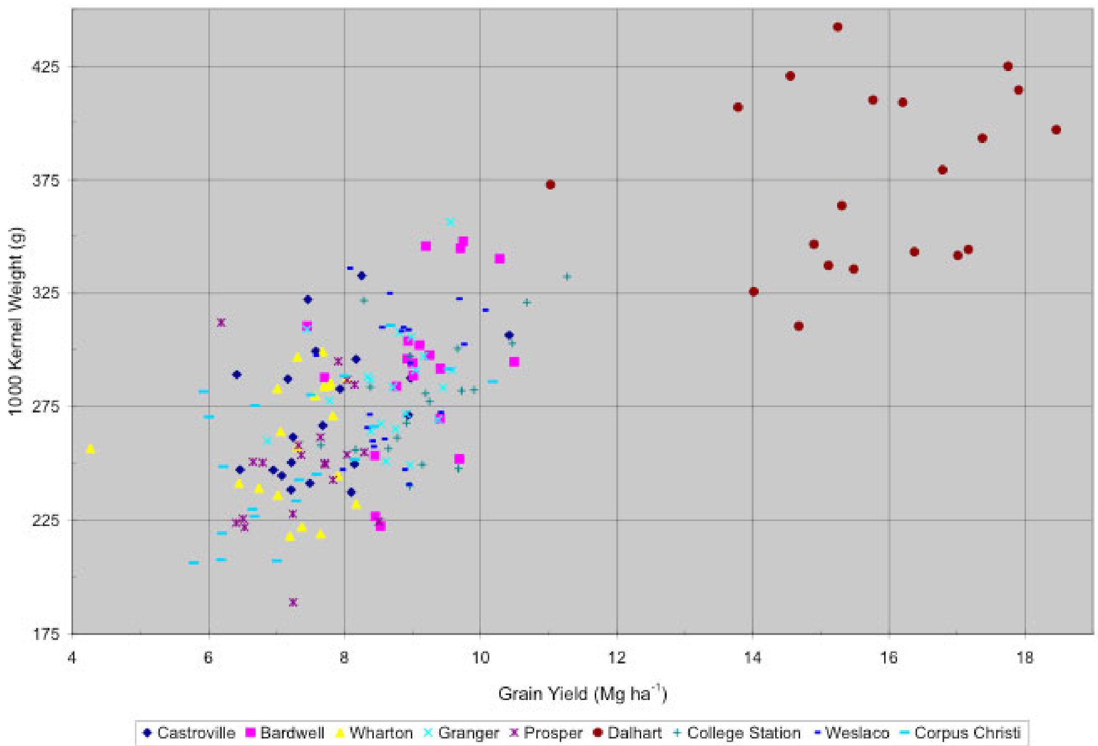


Figure 20. 1000 kernel weight means vs. grain yield means at different environments in Texas for Argentine and U.S. hybrids.

The relationship between test weight and 1000 kernel weight is also indistinguishable from this data (Figure 21). Environments seem to behave more similarly, as Dalhart is not as distinguishable except for higher 1000 kernel weights, and its data points cluster closer to the other environments.

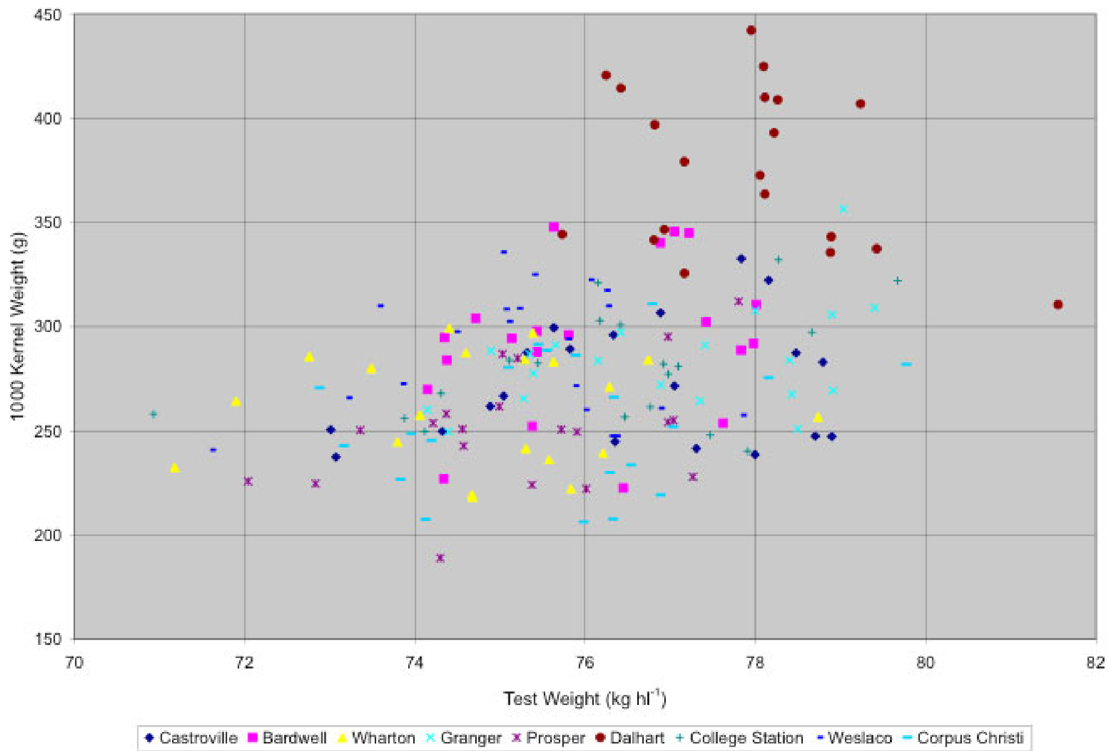


Figure 21. Test weight means vs. 1000 kernel weight means at different environments in Texas for Argentine and U.S. hybrids.

Stability Analysis

Regression stability parameters for grain yield, test weight, and 1000 kernel weight are reported below. For grain yield the range in slopes was from 0.75 to 1.25 with value of 1 being most stable (Table 18). For test weights, the range was 0.60 to 1.48. For 1000 kernel weights the range was 0.35 to 1.67. Argentine hybrids appear more stable across environments in Texas for grain yield, although they have lower overall yields (Figure 22) (Table 18). Argentine hybrids NK900TDMAX, AX884IT, and

AX890MG were the most stable hybrids for grain yield. W4700 was the most stable U.S. hybrid for grain yield, and was also the lowest yielding U.S. hybrid.

Table 18. Regression stability parameters for hybrids across environments in Texas for Argentine and U.S. hybrids.

	Grain Yield		1000 Kernel Weight		Lab Test Weights	
	Slope	Sum of Residuals^2	Slope	Sum of Residuals^2	Slope	Sum of Residuals^2
A933	0.85	4.59	0.71	1092.35	1.67	5.02
AX877	1.13	6.58	0.84	1465.61	1.31	9.68
AX878	0.87	5.22	0.82	536.37	1.50	4.24
AX882	1.12	2.98	1.28	2184.20	1.20	10.89
AX884IT	0.97	3.70	1.48	1164.97	1.23	2.77
AX888IT	0.84	7.27	1.13	3408.91	0.97	4.09
AX889	1.14	3.18	1.16	1406.61	0.78	5.85
AX934	1.07	6.71	0.84	3337.57	0.97	6.91
AX956	0.89	8.93	1.07	1454.60	1.61	5.08
AX882MG	1.11	2.38	1.23	1176.08	1.34	4.26
AX890MG	1.04	4.86	1.37	1562.02	0.90	7.72
DK682	0.91	0.55	0.78	3627.51	1.45	9.34
CONDOR	1.17	2.59	0.95	894.26	0.42	5.45
NK900TDMAX	1.01	4.18	1.14	2120.18	0.89	4.13
AGRI124	0.75	10.50	0.69	3095.17	0.35	15.70
DKC66-80	0.93	6.51	0.74	886.49	0.82	0.79
DKC69-70	1.25	2.40	0.91	3718.72	0.96	10.10
P31B13	1.15	6.05	1.15	1821.13	0.29	4.37
P32R25	0.78	5.46	1.12	1843.82	0.64	5.82
W4700	1.04	6.56	0.60	2304.37	0.68	7.54

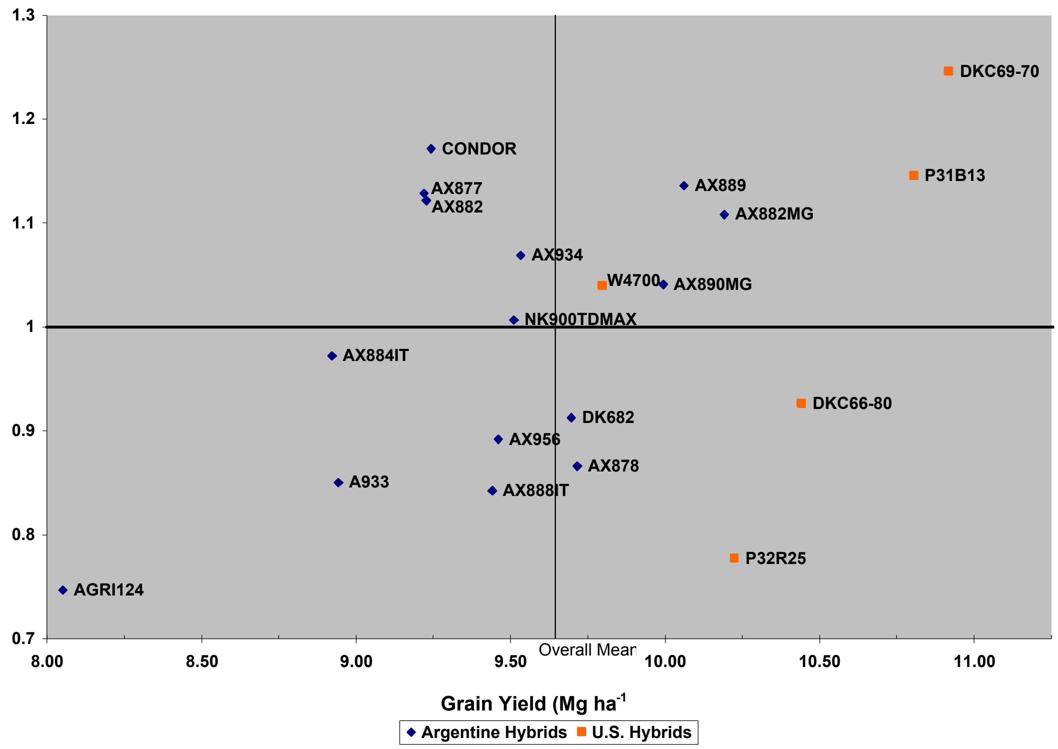
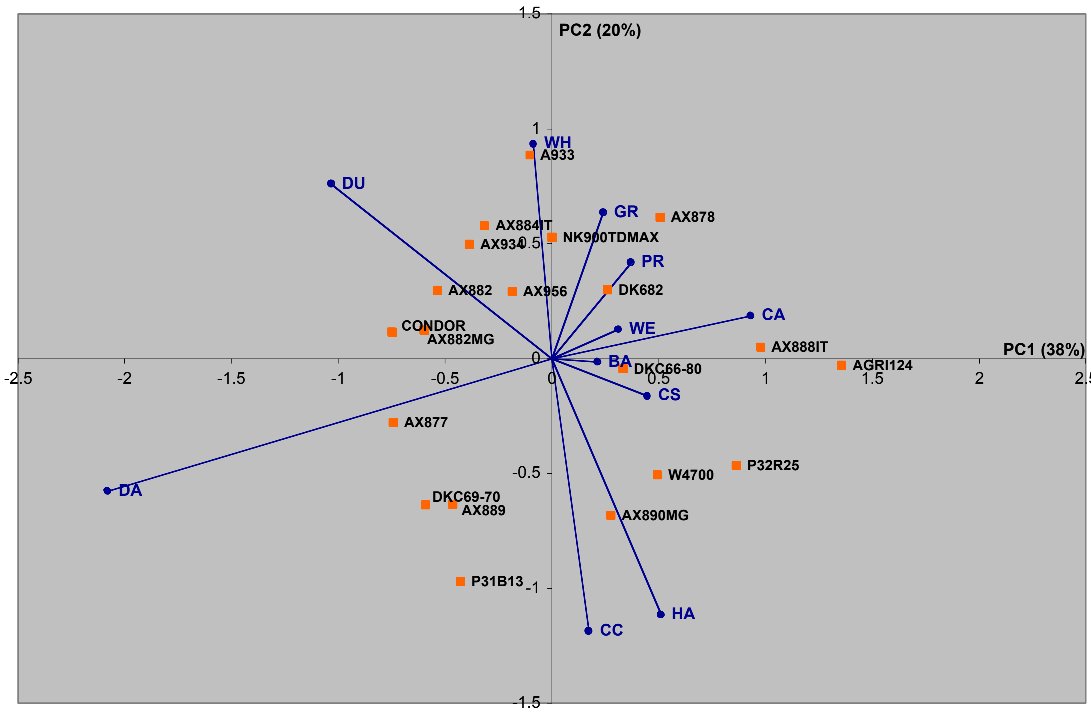


Figure 22. Grain yield vs. regression slope for Argentine and U.S. hybrids across Texas environments.

The SVD biplot for grain yield shows some environmental groupings (Figure 23). Wharton, Granger, and Prosper (rain fed environments) grouped close to each other, and Dalhart and Dumas (high yielding, high plains environments) were close to each other and had longer vectors than other environments (Figure 23). Hybrid points that are close to environment vectors show adaptation to that environment for a particular trait. Overall, the SVD biplot explains 58% of the variation.



CA=Castroville, BA=Bardwell, WH=Wharton, PR=Prosper, GR=Granger, HA=Halfway, DU=Dumas, DA=Dalhart, CS=College Station, WE=Weslaco, CC=Corpus Christi.

Figure 23. Singular value decomposition biplot for grain yield across Texas environments for Argentine and U.S. hybrids.

Slope and means are presented in similar fashion for test weights, and there is a much greater range in slopes although there are several hybrids that had slopes close to 1 (Figure 24) (Table 18). Hybrids AX888IT and DKC69-70 had slopes very near 1 and high test weights. Hybrids AX934, and NK900TDMAX had slopes near 1 and test weights above the overall mean. AX890MG had slope near 1 and had test weight mean just under the overall mean (Figure 24).

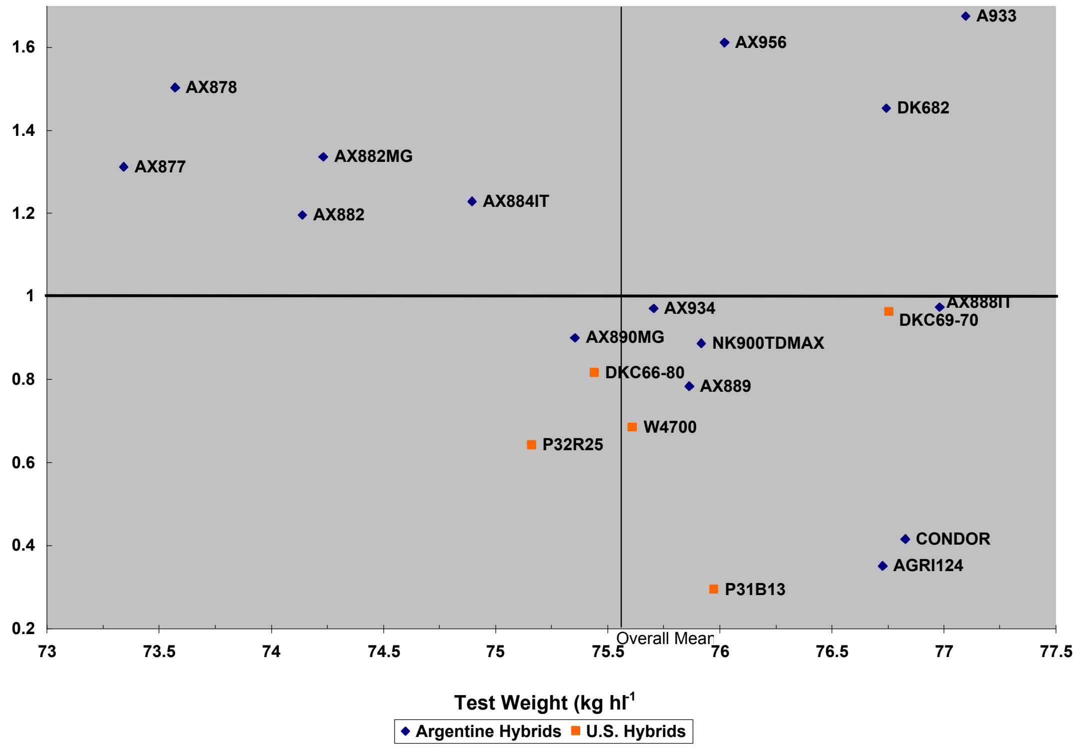
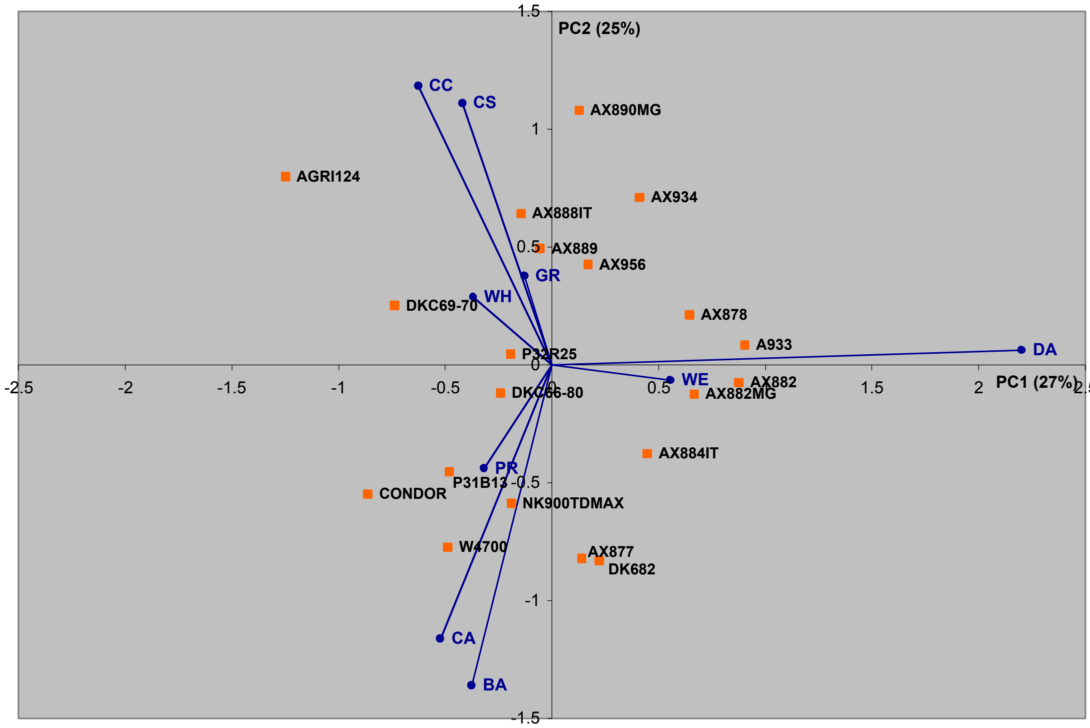


Figure 24. Test weights vs. regression slope for Argentine and U.S. hybrids across Texas environments.

The SVD biplot for test weight shows strong grouping for environments. Prosper, Castroville, and Bardwell group together (Figure 25). Wharton, Granger, Corpus Christi, and College Station also group together. Dalhart and Weslaco represent an additional group. The SVD biplot explained 52% of the variation among environments for test weight.



CA=Castroville, BA=Bardwell, WH=Wharton, PR=Prosper, GR=Granger, DA=Dalhart, CS=College Station, WE=Weslaco, CC=Corpus Christi.

Figure 25. Singular value decomposition biplot for test weight across Texas environments for Argentine and U.S. hybrids.

For 1000 kernel weight, Argentine hybrids AX956, CONDOR, AX888IT, and NK900TDMAX, along with U.S. hybrids DKC69-70 and P32R25 were most stable across environments (Figure 26) (Table 18). The U.S. hybrids showed higher 1000 kernel weight means than Argentine hybrids (Figure 26). Hybrid AX888IT had 1000 kernel weight mean slightly higher than the overall test mean and slope near 1 (Figure 26).

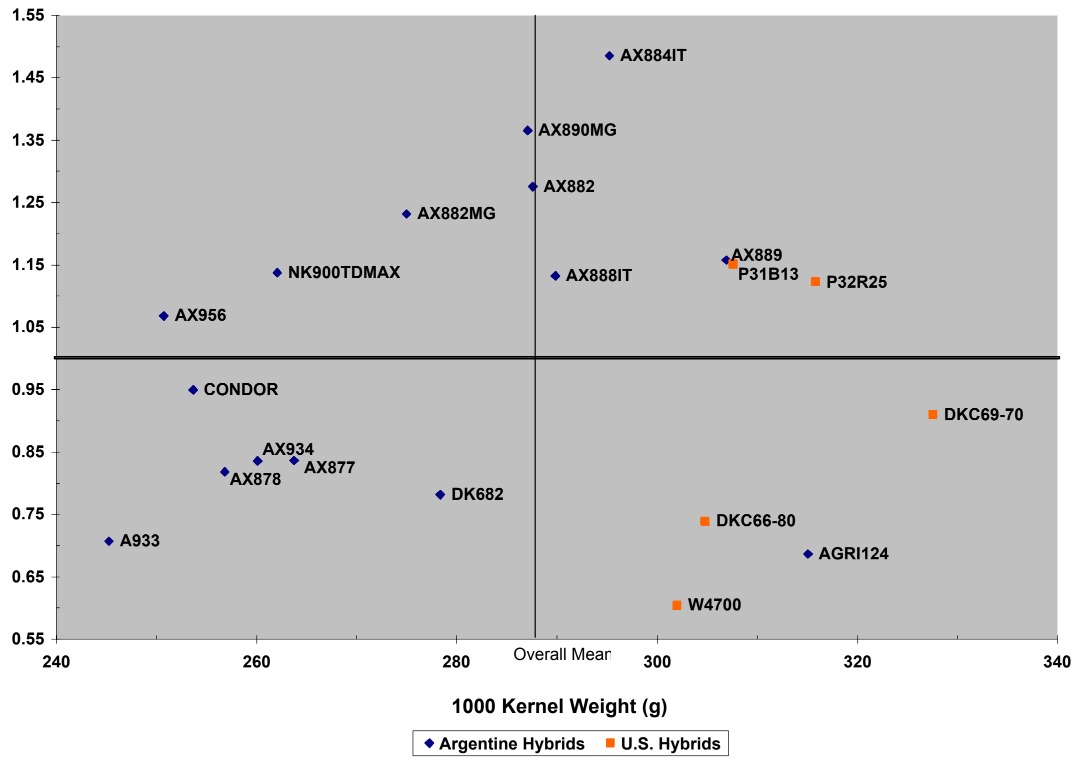


Figure 26. 1000 kernel weights vs. regression slope across Texas environments for Argentine and U.S. hybrids.

The SVD biplot for 1000 kernel weights showed three distinct groupings for environments (Figure 27). Castroville, College Station, Granger, Prosper, and Weslaco behaved similarly, and Bardwell, Corpus Christi, and Wharton behaved similarly. Dalhart behaved differently from all other environments, and had the longest ray indicating heavy 1000 kernel weight means with large amount of variation (Figure 27). The SVD biplot explained 53% of the variation.

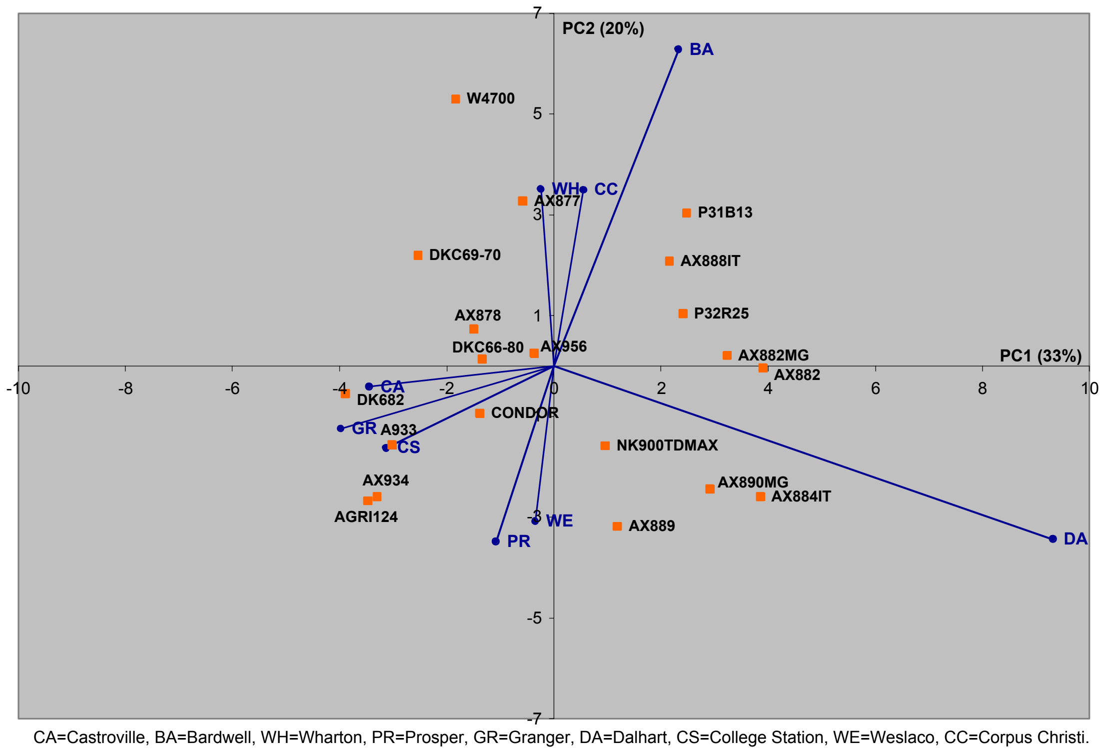
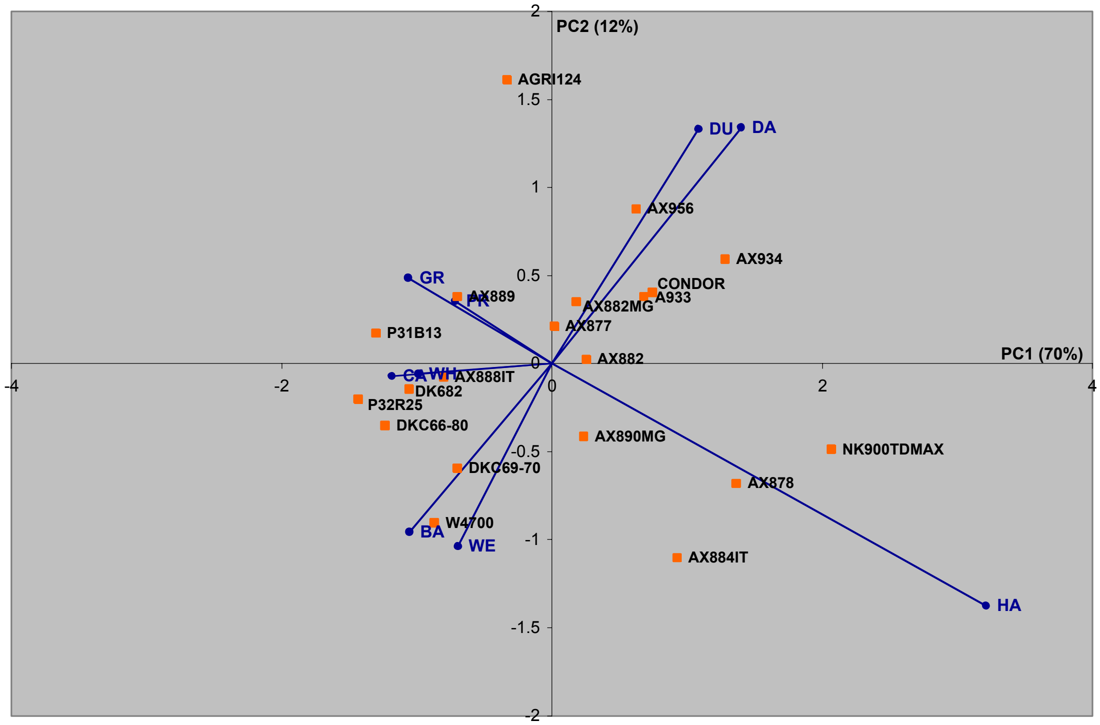


Figure 27. Singular value decomposition biplot for 1000 kernel weights across Texas environments for Argentine and U.S. hybrids.

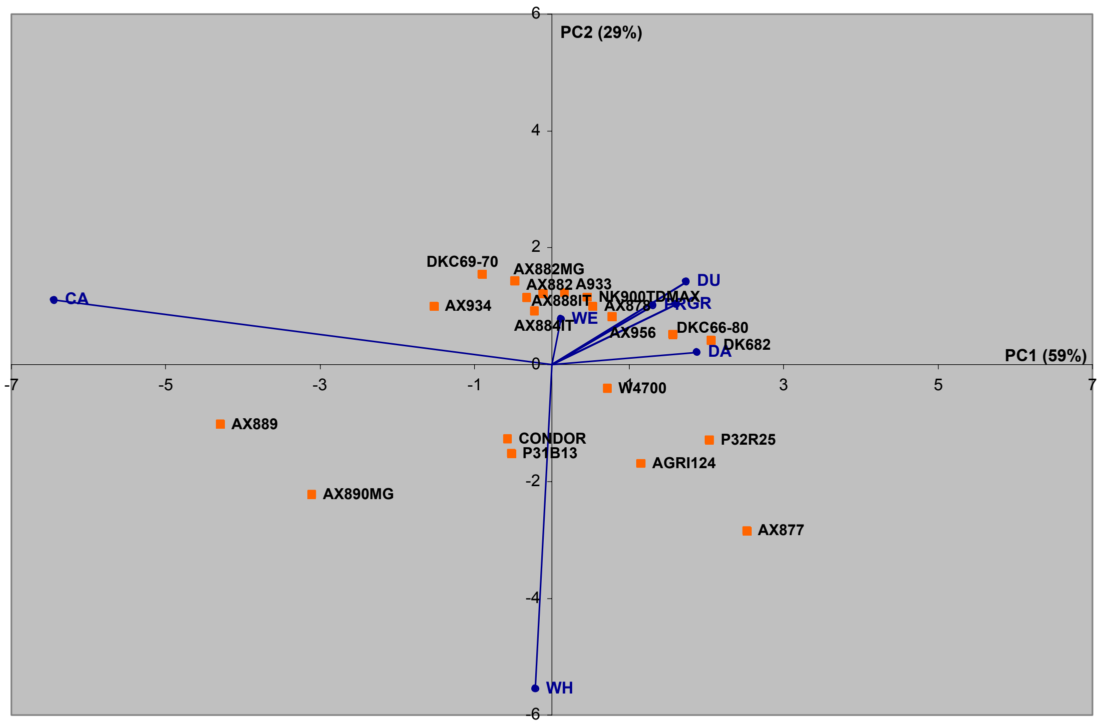
For grain moisture, there were three main clusters of environments (Figure 28). Dalhart and Dumas behaved similarly for grain moisture, but Halfway seemed to perform unlike other environments, although these three environments had the highest overall grain moisture means and are all high plains environments (Figure 28) (Table 15). Bardwell, Castroville, Wharton, and Weslaco behaved similarly for grain moisture, and Prosper, Granger, Wharton, and Bardwell also grouped together. The SVD biplot explained 82% of the variation.



CA=Castroville, BA=Bardwell, WH=Wharton, PR=Prosper, GR=Granger, HA=Halfway, DU=Dumas, DA=Dalhart, WE=Weslaco.

Figure 28. Singular value decomposition biplot for grain moisture across Texas environments for Argentine and U.S. hybrids.

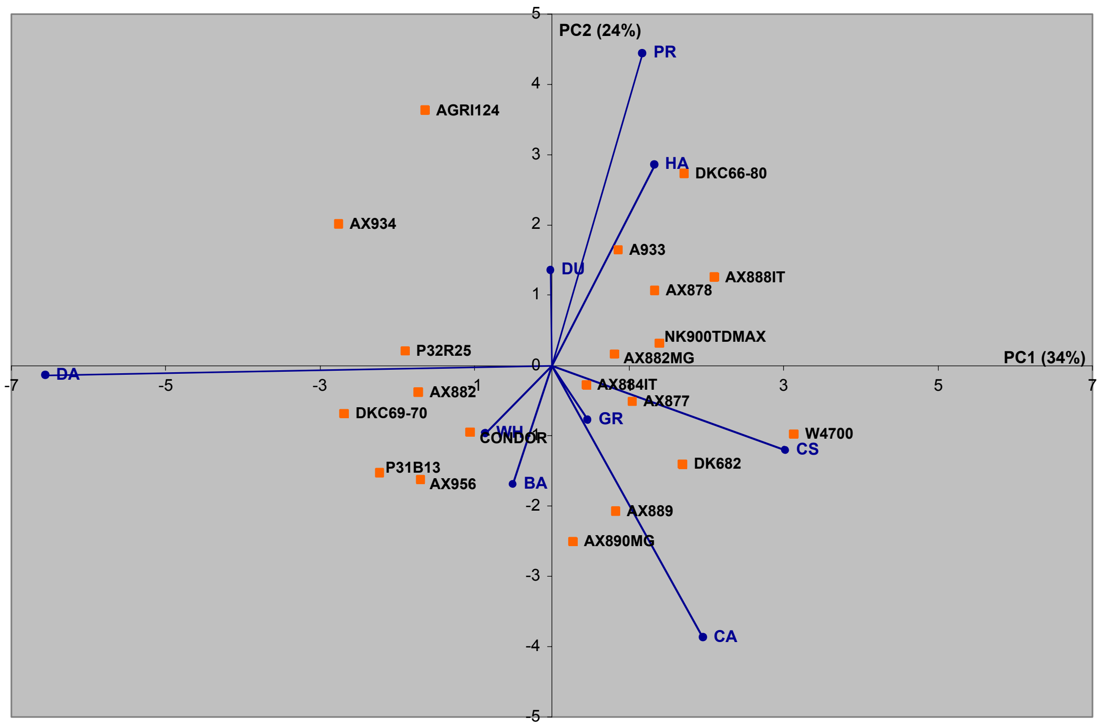
For lodging percentage, there were three groups among environments, with both Castroville and Wharton not showing relationships with other environments (Figure 29). These two environments had the highest lodging percentage, and the other grouping with environments Weslaco, Dumas, Prosper, Granger, and Dalhart had low incidence of lodging. The SVD biplot explained 88% of the variation.



CA=Castroville, WH=Wharton, PR=Prosper, GR=Granger, DU=Dumas, DA=Dalhart, WE=Weslaco.

Figure 29. Singular value decomposition biplot for lodging across Texas environments for Argentine and U.S. hybrids.

For plant height, there were three main groups of environments, with Dalhart, Wharton, and Bardwell behaving similarly, and Dumas, Prosper, and Halfway showing relationship (Figure 30). The third group was made up of environments College Station, Granger, Castroville, and Bardwell. The SVD biplot explained 58% of the variation.



CA=Castroville, BA=Bardwell, WH=Wharton, PR=Prosper, GR=Granger, HA=Halfway, DU=Dumas, DA=Dalhart, CS=College Station.

Figure 30. Singular value decomposition biplot for plant height across Texas environments for Argentine and U.S. hybrids.

Discussion and Conclusions

Excellent growing conditions and above average rainfall during 2004 led to higher overall grain yields in Texas. There was a wide range in environmental means for grain yield as well as hybrid differences in many environments and across environments. In addition, the Argentine hybrids and U.S. hybrids as groups had different grain yield means in several environments. Overall the U.S. hybrids had higher overall grain yields, but several of the Argentine hybrids were competitive such as hybrids AX889 and AX882MG that had overall grain yield means over 10 Mg ha^{-1}, comparable with U.S. hybrids.

The Argentine hybrids performed very well for grain yield in Dalhart, Bardwell, and Wharton as 10, 9, and 9 of the Argentine hybrids respectively were not significantly different from the highest yielding entry in those environments. In four environments Argentine hybrids had the highest overall mean, with AX878 yielding the most in Wharton and Prosper, and AX934 having the highest grain yield mean in Granger and Dumas. In environments Castroville, College Station, Corpus Christi, and Weslaco, Argentine hybrids did not show as much competition for grain yield as only one Argentine hybrid (AX889) was not significantly different from the highest mean. Overall the Argentine hybrids show promise, especially in certain environments, for grain yield in Texas.

For test weight, several of the environments showed differences, while overall significant differences ($P<0.05$) were not realized among hybrids. U.S. hybrids showed a smaller range in test weight means both in single environments and across environments, as opposed to the Argentine hybrids, which had some of the heaviest test weights but also some of the lightest. Some of the hybrids had seed appearance similar to U.S. hybrids. In recent years Argentine maize breeding programs have increased the incorporation and use of elite inbreds from the U.S. Corn Belt leading to materials that may show some dent characteristics in the grain. In single environments hybrid AGRI124 had the highest test weight mean in six environments, and A933 had the highest test weight mean in the other three environments. AX888IT had one of the highest means in five environments. Environment played a role in test weight means, as the lightest test weights were found in Wharton, and the heaviest in Dalhart with almost 2.5 kg hl^{-1} difference between them.

For 1000 kernel weight, a similar environmental pattern was evident as again Dalhart had the highest mean for 1000 kernel weight, and Wharton one of the lowest. U.S. hybrids had higher means for 1000 kernel weight, with many greater than 300 grams in individual environments and overall. A few of the Argentine hybrids, such as AX889 and AGRI124, had similar 1000 kernel weight means, but overall the Argentine hybrids had lower 1000 kernel weights and also showed more variation. There also wasn't as much difference between environments for individual hybrid performance for 1000 kernel weight. 1000 kernel weight might be a trait for indirect selection for grain yield though, as it appeared positively correlated in several environments and overall with grain yield. Selection for heavier 1000 kernel weight may be a way to increase grain yield of the Argentine hybrids.

Only two environments, Castroville and Wharton, showed substantial plant lodging among all hybrids, but a few individual hybrids had lodging problems in Dalhart and Dumas. Other than AX889, AX890MG, and AGRI124, which had high percentage of lodging overall, the Argentine hybrids performed similarly to the U.S. hybrids. These hybrids also had taller plants, but other than AGRI124, did not differ by much from the U.S. hybrids for plant height. To make use of Argentine hybrids in a breeding program, lodging percentage would have to be addressed especially for the three hybrids that suffered the most lodging. For most of the Argentine hybrids, plant height means were actually shorter than the U.S. hybrids.

Another potential limiting factor for the Argentine hybrids was grain moisture, and overall the U.S. hybrids had lower grain moisture percentage means than the Argentine hybrids, but again the Argentine material showed more range in moisture. Environments also were quite different for grain moisture and there was over 10% difference between Castroville and Bardwell (less than 12% moisture) compared to Halfway, Dalhart, and Dumas (over 21% moisture). However, hybrids AX877, AX888IT, and DK682 had grain moisture percentage under 15%, and several more Argentine hybrids had grain moisture percent between 15 and 16%.

Correlation between traits varied between environments, but in most environments plant population and 1000 kernel weights were positively correlated with grain yield, grain moisture was positively correlated with test weight, and grain yield was negatively correlated with test weight and grain moisture. This could be useful as selection for heavier 1000 kernel weight could be used to increase grain yield. Also if heavier 1000 kernel weights could be selected while maintaining some of the heavier test weights of the Argentine hybrids, progress could be made for grain yield. Smaller, denser kernels of the Argentine hybrids could be selected for size to try and obtain larger, denser kernels that would compete with the larger, less dense kernels of U.S. hybrids

For stability many of the Argentine hybrids were more stable across individual environments for a variety of traits compared to the U.S. hybrids. Many of the

Argentine hybrids were also less stable than the U.S. hybrids. With such a wide variety of environments being used for testing, the stability of several hybrids would improve greatly if hybrids were targeted for certain groups of environments.

Overall differences were seen in performance of hybrids for different traits in different environments. While the U.S. hybrids were good performers across the state, the Argentine hybrids performed well in several environments and not as well in others. Several of the Argentine hybrids are competitive with U.S. hybrids for grain yield and have heavy test weights. Lodging and grain moisture may be problematic for some of the Argentine hybrids, but could be improved under selection. In addition selection for heavier 1000 kernel weights could improve grain yield performance.

Due to problems with lodging and grain moisture, and the fact that Argentine hybrids were competitive but not the highest yielding hybrids when compared with U.S. hybrids, the Argentine hybrids probably wouldn't be acceptable for use in production agriculture in Texas in their current state. A better use would be to incorporate Argentine materials into U.S. breeding programs and select against lodging, grain moisture, and for heavier 1000 kernel weights and higher yields. Inbreds developed through this selection process would then be readily available to cross with elite U.S. temperate inbreds, or to develop maize populations with exotic alleles from the Argentine germplasm.

CHAPTER IV

LAMA TESTCROSSES

Introduction

Exotic Maize Incorporation

Compared with the many races of maize found worldwide, U.S. temperate maize is believed to have a relatively narrow genetic base. This could be problematic for U.S. maize breeders, as a lack of genetic variation will slow gain for grain yield and quality traits. By incorporating maize germplasm from other sources, such as tropical and subtropical South American maize, genetic variation can potentially be increased in U.S. maize. While new genes for productivity, disease resistance, and quality traits may be available in exotic maize, efforts to make use of this material in U.S. breeding programs have often failed in the past.

One difficulty in incorporating exotic germplasm is the lack of agronomic suitability to U.S. growing conditions, as maturity, grain moisture, and stalk and root lodging are important traits that affect the ability of maize to be machine harvested. Along the same line, it is difficult to cross exotic and U.S maize if the flowering dates are far apart, making exotic maize not immediately useful for inbred development and hybrid production. In addition, by adding genetic variation, one hopes to add favorable alleles to the targeted material without losing favorable alleles from the adapted material, and this can affect the mean performance for grain yield and other traits (Dudley, 1982).

Some programs have tried to address these issues by adapting exotic maize crossing exotic maize with temperate maize to create semi-exotic populations that can then be used for testcrosses or breeding purposes (Crossa and Gardner, 1987; Holland and Goodman, 1995; Holland et al., 1996). Often with a diverse cross, and if the adapted parent has more favorable alleles, the semi-exotic line can then be backcrossed to the adapted parent again, providing faster adaptation, and materials that are easier to work with in the breeding program (Crossa and Gardner, 1987; Dudley, 1982). This is considered introgression, as smaller amounts of the exotic germplasm will be found in the materials that result from the backcrosses and there is a chance that beneficial genes from the exotic maize or the adapted material could be lost during the conversion process, especially when multiple backcrosses are made (Crossa and Gardner, 1987; Holland, 2004; Simmonds, 1993).

Other methods have also been used in order to make use of exotic maize as well. In the Corn Belt, both mass selection for earliness and intermating exotic maize with early inbreds showed reduction in days to silking and ear height after several cycles of selection (Hallauer and Sears, 1972). Other groups have practiced several cycles of selection for adaptation on exotic materials during the inbreeding process to develop U.S. temperate adapted 100% tropical materials (Holley and Goodman, 1988; Lewis and Goodman, 2003; Uhr and Goodman, 1995a; Uhr and Goodman, 1995b).

Subtropical x Temperate Maize Hybrids

By selecting for earliness, decreased plant and ear height, and other agronomically important traits without crossing the exotic maize and adapted materials one can create materials that are 100% exotic germplasm, but are adapted to temperate environments and are then easily incorporated into a breeding program for extraction of inbred lines or population improvement. Several different breeding programs in the U.S. have had varying levels of success by creating 100% tropical adapted lines and using them in hybrids (Castillo-Gonzalez and Goodman, 1989; Crossa and Gardner, 1987; Lewis and Goodman, 2003; Uhr and Goodman, 1995a; Uhr and Goodman, 1995b).

Materials and Methods

Line and Testcross Development

Early generation tropical maize lines from commercial companies in South America were obtained and grown in Weslaco, Texas (a subtropical environment). These materials were then advanced under selection for maturity, grain quality, husk cover, hard endosperm, and standability in nurseries in Weslaco and College Station, Texas during the fall and summer respectively. Selected lines, known as LAMA lines, were 100% tropical maize lines better adapted to southern U.S. environments.

Selected S_4, lines were testcrossed to elite inbred lines LH195 and LH210 (Holden's Foundation Seeds) in 2003 for evaluation during 2004. Due to contamination of LH210 crosses with red kernel maize germplasm, the LH210 crosses were not evaluated or presented in this thesis. Seed shortage also limited the number of entries in several environments, so a balanced dataset of fifteen LAMA testcrosses and five U.S. hybrids are presented below. In the Appendix results for all the LH195 testcrosses are presented for the traits measured (Tables 41-54)(Figure 54).

Experimental Design

Texas environments used for testing ranged from subtropical to temperate and spanned over ten degrees of latitude (Table 2). These environments are representative samples of typical maize production environments in Texas. An alpha lattice design with incomplete blocks was used with either two or three replications per environment. Experimental units consisted of two row plots everywhere but Weslaco, College Station, and Corpus Christi, where one row plots were used. Trials were planted in spring 2004 starting in February and ending in May depending on planting dates for each region. Standard agronomic and cultural practices at each environment were applied.

Traits measured included plant and ear heights, lodging, grain yield, test weights, and grain moisture. Plant height was taken at the end of growing season before harvest by measuring from the ground to the tip of the tassel, and ear height was taken from the ground to the base of the primary ear. Plant population was determined by counting the total number of plants per plot before harvest and converting to plants per hectare. Lodging was taken as both root lodging and stalk lodging and then combined and expressed as a percentage by combining number of plants root and stalk lodged then dividing by the total number of plants in a plot. Grain yield (adjusted to 15.5% grain moisture), grain moisture, and test weights were taken by mounted harvesting equipment in the combine during harvest.

Statistical Analysis

Single environment analysis of variance for grain moisture, grain yield, lodging, plant height, plant population, and test weights was conducted using Proc GLM in SAS

9.0 (SAS Institute, 2002). For all traits, contrasts were computed to compare the overall performance of LAMA testcrosses vs. U.S. hybrids. Hybrid and environmental trait means were determined in SAS 9.0. Correlations among traits were examined using singular value decomposition at each environment.

Analysis of variance across environments was conducted with Proc GLM in SAS. Means across environments were determined using Proc Mixed in SAS 9.0 (SAS Institute, 2002) considering the hybrids as fixed effects, and environments as random effects. Overall means were used to determine trait correlation using SVD. Stability analysis was done using linear regression of hybrids on environmental indices (Eberhart and Russell, 1966; Lipkovich and Smith, 2001).

One of the problems with the analysis of this experiment is seed shortage forced us to substitute lines in some environments and many LAMA testcrosses were not planted in as many environments. For this thesis, a balanced dataset was used with LAMA testcrosses and U.S. hybrids that were present in most of the environments. In the Appendix, additional tables and charts with all LAMA testcrosses and U.S. hybrids can be found.

Results

Single Environment Analysis

ANOVA and Means

For plant population, only Castroville and Wharton had significant differences ($P<0.05$) among hybrids (Table 19). Replications were not significant in any environment, and plant populations should be comparable between replications within environments (Table 19).

Table 19. Analysis of variance for plant population (plants ha^{-1}) at Texas environments for LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS[†]	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square WE	df	Mean Square CC
Reps	1	3.06	1	22.11	1	0.00	1	0.29	1	0.90	1	6.47	2	40.14
Hybrids	19	39.19	19	18.33*	19	23.83*	17	2.73	12	114.95	19	11.15	18	38.15
LAMA TC	14	0.50	14	1.50**	14	0.62	13	0.53	8	6.16**	14	1.02	13	28.00
U.S. Hybrids	4	0.57	4	0.93	4	1.11	3	0.89	3	2.64	4	2.23	4	33.45
LAMA TC*U.S.	1	176.66*	1	21.75	1	7.16	1	12.72	1	163.19	1	0.01	1	188.81*
Error	19	24.70	21	8.05	19	8.80	17	10.79	12	51.78	38	10.79	36	39.06
Repeatability		0.37		0.56		0.63		0.00		0.55		0.03		0.00

*Significant at P<0.05.
** Significant at P<0.01.
[†] CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco, CC=Corpus Christi.

For grain yield, replications within environments were only significant (P<0.05) in one environment, but due to low error terms in all environments, field variation for grain yield was not a problem (Table 20). Grain yield was significantly different (P<0.05) among hybrids in College Station, Castroville, Dumas, Weslaco, and Corpus Christi (Table 20). Significant differences (P<0.05) between U.S. hybrids and LAMA testcrosses were found in Castroville, Dumas, Weslaco, and Corpus Christi. Repeatabilities ranged from .22 to .86 with most environments being above .50 (Table 20).

Table 20. Analysis of variance for grain yield (Mg ha^{-1}) at Texas environments for LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square			df	Mean Square	df	Mean Square	df	Mean Square	
		CS†	CA	WH		BA		DU		WE	CC†
Reps	1	0.11	0.67	0.65	1	0.20	1	2.02	2	3.18*	0.72
Hybrids	19	0.87*	1.34*	0.74	17	0.58	12	5.70**	19	1.57**	3.43**
LAMA TC	14	0.50	1.50**	0.62	13	0.53	8	6.16**	14	1.02	1.74*
U.S. Hybrids	4	0.57	0.93	1.11	3	0.89	3	2.64	4	2.23	0.61
LAMA TC*U.S.	1	7.25**	0.13	1.06	1	0.29	1	11.20**	1	6.62**	36.73**
Error	19	0.34	0.58	0.38	17	0.45	12	0.81	38	0.64	0.69
Repeatability		0.60	0.57	0.49		0.22		0.86		0.59	0.80

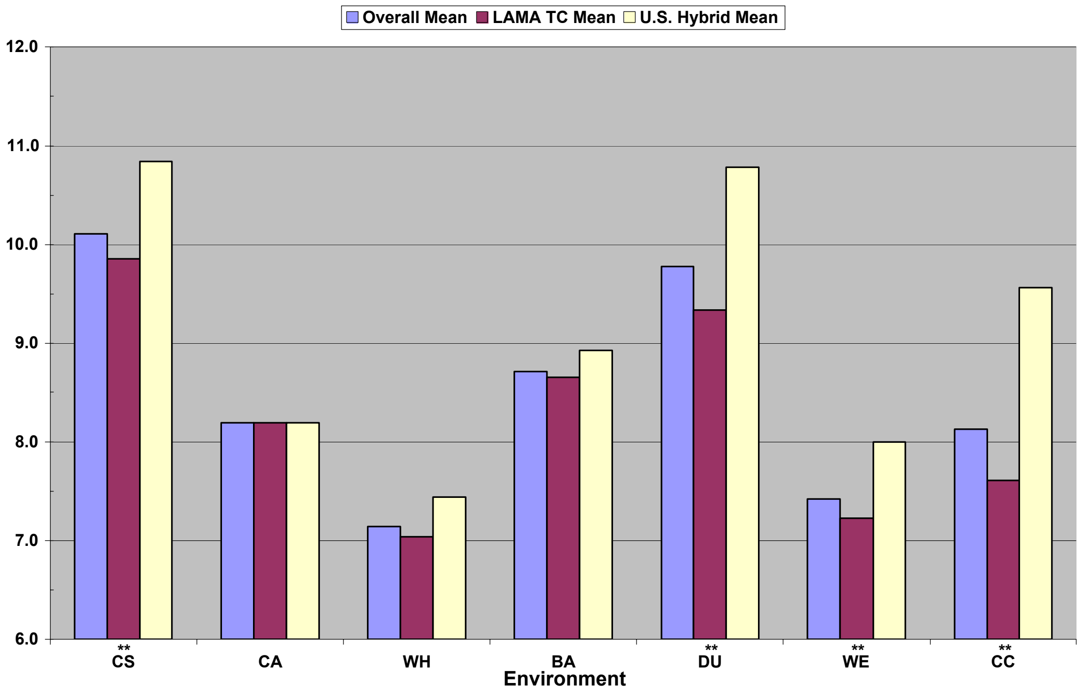
* Significant at $P<0.05$.
** Significant at $P<0.01$.
† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco, CC=Corpus Christi.

With excellent overall grain yields during the summer of 2004, environments College Station and Dumas had the highest overall grain yield, and Wharton and Weslaco had the lowest grain yield (Table 21) (Figure 31). U.S. hybrids had higher grain yield means than LAMA testcrosses in all environments except Castroville, where they were the same (Figure 31). Coefficients of variation values were all less than 11%.

Table 21. Grain yield means (Mg ha^{-1}) for LAMA testcrosses and U.S. hybrids at each environment.

	----------Mg ha^{-1}----------						
	CS[†]	CA	WH	BA	DU	WE	CC
TX-LAMA2002-2-1-B/LH195	9.13	6.29	7.22	8.51	----	7.78	8.42
TX-LAMA2002-5-3-B/LH195	9.85	8.94	7.43	8.86	----	6.45	7.68
TX-LAMA2002-6-1-B/LH195	10.38	7.91	7.48	8.68	11.27	7.54	8.14
TX-LAMA2002-9-2-B/LH195	10.19	9.53	7.83	9.34	11.63	7.10	7.96
TX-LAMA2002-12-1-B/LH195	9.41	8.71	6.79	9.06	----	8.14	7.20
TX-LAMA2002-13-B2-B/LH195	9.61	6.76	6.60	8.12	6.81	6.87	7.05
TX-LAMA2002-14-B-B/LH195	9.94	7.22	6.64	9.73	9.86	6.51	7.79
TX-LAMA2002-17-2-B/LH195	9.68	8.05	6.46	8.22	10.57	7.93	8.16
TX-LAMA2002-20-4-B/LH195	10.15	8.32	7.23	8.14	8.36	7.48	7.67
TX-LAMA2002-22-2-B/LH195	10.19	8.54	6.63	8.77	9.03	6.86	7.71
TX-LAMA2002-25-5-B/LH195	10.12	7.42	7.99	8.05	----	6.87	7.63
TX-LAMA2002-42-B-B/LH195	9.69	9.59	7.35	8.46	9.21	6.76	8.22
TX-LAMA2002-44-B-B/LH195	9.11	8.69	5.88	----	----	7.52	----
TX-LAMA2002-46-3-B/LH195	9.47	8.44	7.49	8.70	7.28	7.64	7.38
TX-LAMA2002-58-1-B/LH195	10.98	8.51	6.63	8.52	----	6.94	5.57
DKC66-80	10.95	8.92	7.63	8.99	9.49	8.29	9.14
DKC69-70	11.27	7.94	7.62	9.79	11.67	9.24	9.47
P31B13	11.35	8.23	7.89	8.25	11.21	7.87	10.19
P32R25	10.05	7.90	7.70	8.69	10.76	7.44	9.43
LH195 x LH210	10.59	7.96	6.36	----	----	7.16	9.58
Overall Mean	10.10	8.19	7.14	8.71	9.78	7.42	8.13
LSD (0.05)[‡]	1.23*	1.59*	1.28	1.41	1.96**	1.36**	1.43**
C.V., %	5.80	9.26	8.61	7.74	9.14	10.75	10.26

* Significant at P<0.05
** Significant at P<0.01
[†] CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco, and CC=Corpus Christi.
[‡] Fisher's least significant difference, use to compare individual hybrids.



* Significant difference P<0.05 between LAMA TC Mean and U.S. Hybrid Mean.
** Significant difference P<0.01 between LAMA TC Mean and U.S. Hybrid Mean.
CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco, CC=Corpus Christi.

Figure 31. Grain yield means for all hybrids, LAMA testcrosses, and U.S. hybrids across environments.

For test weight, no environments had significant differences (P<0.05) among replications (Table 22). Test weights were significantly different (P<0.05) among hybrids in all environments, and were significantly different (P<0.05) between U.S. hybrids and LAMA testcrosses in all environments except Dumas (Table 22). Repeatabilities were high, ranging from .53 to .95, indicating that differences among hybrids were due mainly to genotypic differences (Table 22).

Table 22. Analysis of variance for test weight (kg hl^{-1}) at Texas environments for LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square			df	Mean Square	df	Mean Square	df	Mean Square
		CS†	CA	WH		BA		DU		WE
Reps	1	0.10	0.30	0.00	1	0.14	1	1.59	2	0.45
Hybrids	19	4.65**	3.80**	6.32**	17	2.91**	12	1.65*	19	5.20**
LAMA TC	14	2.37**	2.60**	3.35	13	1.88**	8	2.15*	14	5.82**
U.S. Hybrids	4	2.14	1.55*	2.20	3	2.49	3	0.80	4	2.58**
LAMA TC*U.S.	1	46.59**	24.81**	64.33**	1	17.63**	1	0.19	1	6.92**
Error	19	0.22	0.51	2.97	17	0.56	12	0.47	36	0.54
Repeatability		0.95	0.87	0.53		0.81		0.72		0.90

* Significant at P<0.05.
** Significant at P<0.01.
† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.

Environments College Station and Castroville had the highest test weights, while environments Wharton and Dumas had the lowest test weights (Table 23) (Figure 32). In all environments except Dumas, LAMA testcrosses had higher test weight means than U.S. hybrids (Table 23). Coefficients of variation values were very low, all environments less than 1% except for Wharton where it was 2.27%.

Table 23. Test weight means (kg hl^{-1}) for LAMA testcrosses and U.S. hybrids at each environment.

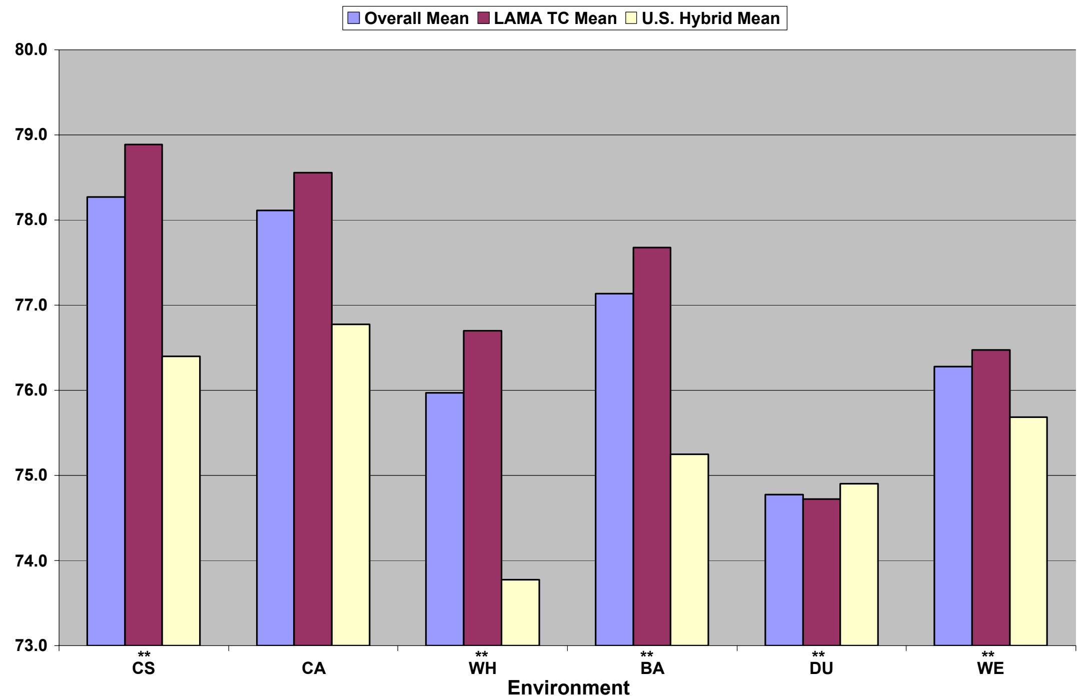
	kg hl^{-1}					
	CS†	CA	WH	BA	DU	WE
TX-LAMA2002-2-1-B/LH195	79.22	77.88	77.81	78.44	----	77.05
TX-LAMA2002-5-3-B/LH195	77.79	77.46	76.27	76.58	----	74.98
TX-LAMA2002-6-1-B/LH195	76.17	76.61	75.35	76.21	72.72	73.94
TX-LAMA2002-9-2-B/LH195	79.19	79.40	77.63	77.49	75.94	77.61
TX-LAMA2002-12-1-B/LH195	79.44	77.99	74.90	77.84	----	76.87
TX-LAMA2002-13-B2-B/LH195	78.60	79.91	76.73	77.99	73.88	76.03
TX-LAMA2002-14-B-B/LH195	80.29	78.74	76.74	78.78	75.42	77.66
TX-LAMA2002-17-2-B/LH195	78.37	77.24	75.50	77.29	75.42	76.87
TX-LAMA2002-20-4-B/LH195	79.68	79.86	76.75	78.82	74.39	76.07
TX-LAMA2002-22-2-B/LH195	79.51	79.31	75.11	78.45	74.90	74.84
TX-LAMA2002-25-5-B/LH195	77.55	76.95	75.24	75.66	----	74.72
TX-LAMA2002-42-B-B/LH195	79.35	79.53	77.04	77.64	74.13	76.09
TX-LAMA2002-44-B-B/LH195	80.13	80.50	78.68	----	----	78.98
TX-LAMA2002-46-3-B/LH195	79.58	79.54	78.52	78.24	75.68	77.31
TX-LAMA2002-58-1-B/LH195	78.48	77.42	78.30	78.01	----	78.10
DKC66-80	75.79	76.08	73.98	74.58	74.65	74.95
DKC69-70	77.64	77.84	72.25	76.31	75.42	77.25
P31B13	77.41	77.30	74.19	75.04	74.13	75.58
P32R25	75.51	76.37	73.36	75.04	75.42	75.62
LH195 x LH210	75.64	76.28	75.11	----	----	75.03
Overall Mean	78.26	78.11	75.97	77.13	74.77	76.28
LSD (0.05)‡	0.98**	1.49**	3.61**	1.57**	1.49*	1.25**
C.V., %	0.60	0.91	2.27	0.97	0.91	0.96

* Significant at P<0.05

** Significant at P<0.01

† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.

‡ Fisher's least significant difference, use to compare individual hybrids.



* Significant difference P<0.05 between LAMA TC Mean and U.S. Hybrid Mean.
** Significant difference P<0.01 between LAMA TC Mean and U.S. Hybrid Mean.
CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.

Figure 32. Test weight means for all hybrids, LAMA testcrosses, and U.S. hybrids across environments.

For lodging percentage, replications within environments were not significant (P<0.05) in any environment, and error terms were low everywhere but College Station and Castroville, indicating field variation wasn't an issue for lodging percentage (Table 24). Environments Wharton and Weslaco had significant differences (P<0.05) among hybrids. Significant differences (P<0.05) between U.S. hybrids and LAMA testcrosses were found in College Station and Weslaco. Repeatabilities were variable and ranged from .00 to .72 (Table 24).

Table 24. Analysis of variance for lodging (%) at Texas environments for LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS[†]	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square WE
Reps	1	0.43	1	116.43	1	18.50	1	0.26	1	32.82	2	12.95
Hybrids	19	225.57	19	127.49	19	25.83**	17	0.26	12	11.76	19	116.33**
LAMA TC	14	243.14	14	117.13**	14	33.52**	13	0.00	8	7.28	14	131.44**
U.S. Hybrids	4	28.99	4	154.43	4	4.59	3	1.15	3	27.14	4	0.79
LAMA TC*U.S.	1	766.03*	1	289.40	1	3.14	1	0.89	1	1.43	1	366.97**
Error	19	129.94	21	68.97	19	8.32	17	0.26	12	13.05	38	32.68
Repeatability		0.42		0.46		0.68		0.00		0.00		0.72

* Significant at P<0.05.
** Significant at P<0.01.
[†] CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.

For lodging percentage, Castroville and College Station had the highest lodging percentages, and Bardwell and Wharton had the lowest means (Table 25) (Figure 33). In College Station and Weslaco where significant differences between U.S. hybrids and LAMA testcrosses were detected, the LAMA testcrosses had higher means for lodging (Table 24)(Table 25). Coefficients of variation values were high for all environments and ranged from 69.5% to 600.0%.

Table 25. Lodging means (%)for LAMA testcrosses and U.S. hybrids at each environment.

	-------------------------------	-----	---	%	-----	-------------------------------
	CS†	CA	WH	BA	DU	WE
TX-LAMA2002-2-1-B/LH195	19.45	18.81	0.00	0.00	----	3.53
TX-LAMA2002-5-3-B/LH195	28.72	12.40	3.39	0.00	----	24.19
TX-LAMA2002-6-1-B/LH195	0.00	16.20	1.06	0.00	4.38	0.00
TX-LAMA2002-9-2-B/LH195	19.79	15.14	4.37	0.00	3.53	5.34
TX-LAMA2002-12-1-B/LH195	28.00	0.00	16.18	0.00	----	3.03
TX-LAMA2002-13-B2-B/LH195	4.81	28.20	0.52	0.00	4.33	3.90
TX-LAMA2002-14-B-B/LH195	7.61	4.74	0.00	0.00	5.84	2.90
TX-LAMA2002-17-2-B/LH195	36.29	6.05	0.00	0.00	0.00	0.72
TX-LAMA2002-20-4-B/LH195	4.30	0.63	0.95	0.00	6.28	2.97
TX-LAMA2002-22-2-B/LH195	7.56	4.10	0.00	0.00	3.65	7.61
TX-LAMA2002-25-5-B/LH195	11.65	22.53	1.44	0.00	----	2.50
TX-LAMA2002-42-B-B/LH195	21.80	9.19	0.91	0.00	3.71	6.51
TX-LAMA2002-44-B-B/LH195	10.13	10.46	1.60	----	----	10.01
TX-LAMA2002-46-3-B/LH195	11.27	9.09	0.00	0.00	3.32	18.30
TX-LAMA2002-58-1-B/LH195	10.31	0.53	2.97	0.00	----	5.12
DKC66-80	5.55	9.08	0.00	0.00	5.46	1.45
DKC69-70	3.64	26.97	0.49	0.00	1.58	0.74
P31B13	12.97	19.46	1.07	0.00	1.05	0.00
P32R25	0.00	17.77	2.86	1.52	5.72	0.76
LH195 x LH210	2.52	12.01	3.48	----	----	0.71
Overall Mean	12.27	12.14	2.06	0.08	3.67	5.01
LSD (0.05)‡	23.86	17.38	6.04**	1.06	7.87	9.77**
C.V., %	94.37	69.53	139.84	600.00	102.05	114.00

* Significant at P<0.05
** Significant at P<0.01
† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.
‡ Fisher's least significant difference, use to compare individual hybrids.

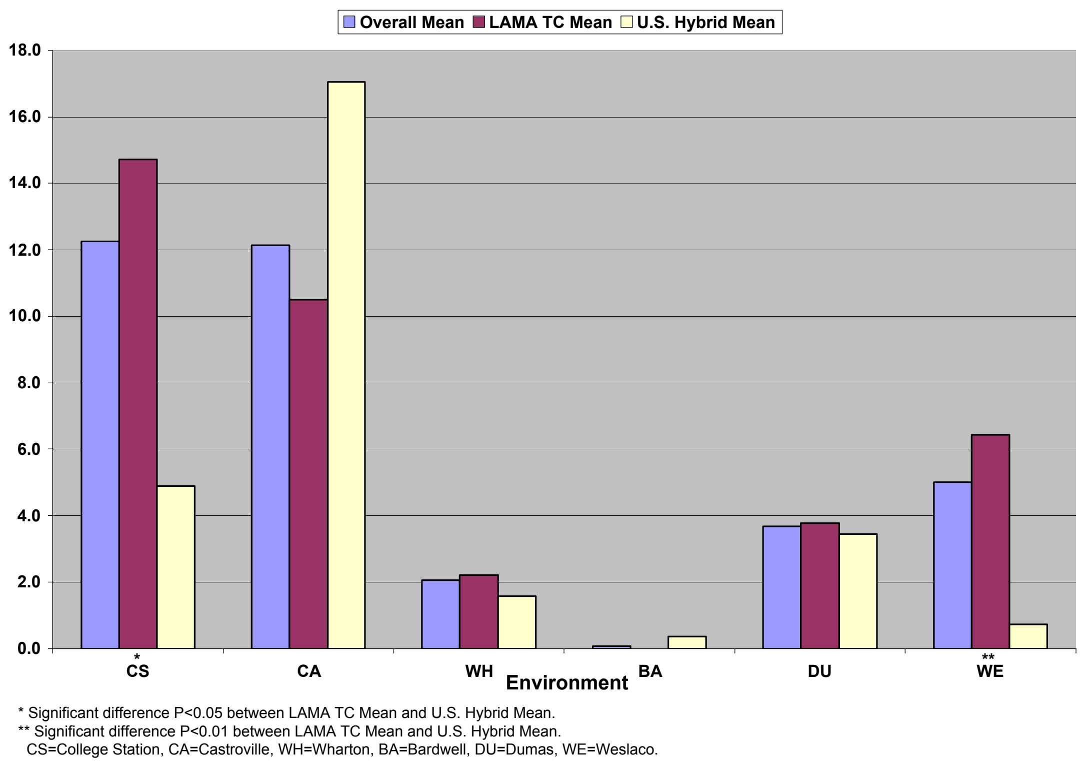


Figure 33. Lodging percentage means for all hybrids, LAMA testcrosses, and U.S. hybrids across environments.

For plant height, replications within environments were significant (P<0.05) only in Bardwell and College Station (Table 26). Plant heights were significantly different (P<0.05) among hybrids in Castroville, Bardwell, Wharton, and College Station. Significant differences (P<0.05) between LAMA testcrosses and U.S. hybrids were detected in Wharton, Bardwell, and College Station. Repeatabilities were mostly high and ranged from .33 to .80.

Table 26. Analysis of variance for plant height (cm) at Texas environments for LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS[†]	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square CS
Reps	1	4.03	1	18.59	1	85.32	1	301.25*	1	20.10	2	419.03*
Hybrids	19	158.33	19	208.80*	19	206.88**	17	252.85**	12	164.72	19	311.28**
LAMA TC	14	186.02	14	271.37**	14	220.68**	13	267.30**	8	188.53	14	356.64**
U.S. Hybrids	4	100.97	4	41.94	4	50.65	3	40.86	3	82.53	4	69.46
LAMA TC*U.S.	1	0.05	1	1.45	1	638.76**	1	700.92**	1	220.85	1	643.58*
Error	19	106.24	21	83.14	19	48.31	17	50.02	12	71.17	38	112.18
Repeatability		0.33		0.60		0.77		0.80		0.57		0.64

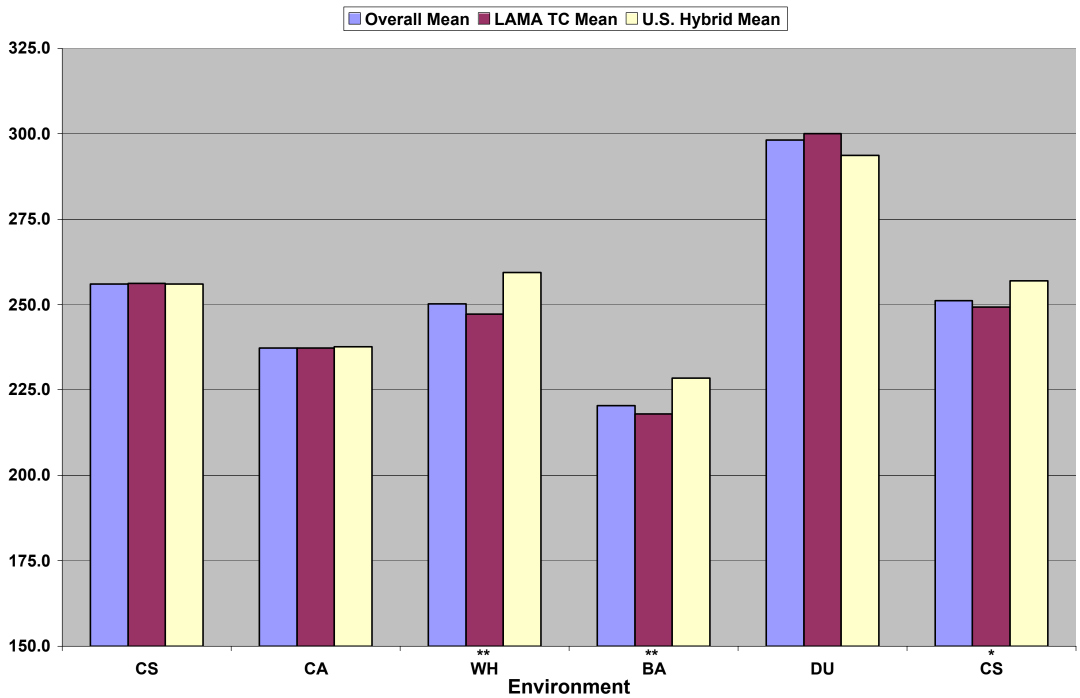
* Significant at P<0.05.
** Significant at P<0.01.
[†] CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, CA=College Station.

Environments Dumas and College Station had the tallest plants and environments Castroville and Bardwell had the shortest plants (Table 27) (Figure 34). In Wharton, Bardwell, and College Station there were significant differences between LAMA testcrosses and U.S. hybrids, with LAMA testcrosses being shorter than U.S. hybrids (Figure 34). Coefficients of variation values were low (less than 5%) in all environments.

Table 27. Plant height means (cm) for LAMA testcrosses and U.S. hybrids at each environment.

	---------------	---------------	-------cm-------	---------------	---------------	---------------
	CS[†]	CA	WH	BA	DU	CS
TX-LAMA2002-2-1-B/LH195	243.84	218.44	238.72	209.55	----	248.06
TX-LAMA2002-5-3-B/LH195	260.35	232.41	244.07	220.98	----	249.77
TX-LAMA2002-6-1-B/LH195	259.08	243.84	254.32	222.25	308.61	255.70
TX-LAMA2002-9-2-B/LH195	261.62	252.73	259.54	233.68	308.61	256.54
TX-LAMA2002-12-1-B/LH195	265.43	254.00	271.68	234.95	----	270.08
TX-LAMA2002-13-B2-B/LH195	236.22	223.52	235.36	205.74	292.10	238.76
TX-LAMA2002-14-B-B/LH195	242.57	222.25	231.42	196.85	294.64	229.45
TX-LAMA2002-17-2-B/LH195	262.89	236.22	251.58	214.63	311.15	263.32
TX-LAMA2002-20-4-B/LH195	247.65	229.87	238.16	205.74	281.94	231.15
TX-LAMA2002-22-2-B/LH195	257.81	238.76	245.31	229.87	303.53	241.29
TX-LAMA2002-25-5-B/LH195	254.00	229.87	247.75	210.82	----	252.30
TX-LAMA2002-42-B-B/LH195	265.43	247.65	244.28	214.63	304.80	252.30
TX-LAMA2002-44-B-B/LH195	259.08	252.73	237.84	----	----	248.07
TX-LAMA2002-46-3-B/LH195	270.51	245.11	249.41	228.60	294.64	254.00
TX-LAMA2002-58-1-B/LH195	255.27	232.41	260.07	223.52	----	248.92
DKC66-80	248.92	236.22	254.36	222.25	297.18	249.78
DKC69-70	250.19	234.95	259.43	228.60	288.29	260.79
P31B13	266.70	233.68	256.02	232.41	288.29	259.93
P32R25	256.54	245.11	262.26	231.14	300.99	259.93
LH195 x LH210	257.81	238.76	264.60	----	----	254.02
Overall Mean	256.10	237.43	250.31	220.35	298.06	251.21
LSD (0.05)[‡]	21.57	19.08*	14.55**	14.86**	18.38	18.10**
C.V., %	4.02	3.84	2.77	3.21	2.83	4.22

* Significant at P<0.05
** Significant at P<0.01
[†] CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, CS=College Station.
[‡] Fisher's least significant difference, use to compare individual hybrids.



* Significant difference P<0.05 between LAMA TC Mean and U.S. Hybrid Mean.
** Significant difference P<0.01 between LAMA TC Mean and U.S. Hybrid Mean.
CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, CS=College Station.

Figure 34. Plant height means for all hybrids, LAMA testcrosses, and U.S. hybrids across environments.

For grain moisture, only Weslaco had significant differences (P<0.05) between replications (Table 28). Significant differences (P<0.05) among hybrids were detected in all environments, as well as significant differences (P<0.05) between LAMA testcrosses and U.S. hybrids. Repeatabilities were very high and ranged from .74 to .97, indicating that differences among hybrids for grain moisture were due mainly to genotypic differences.

Table 28. Analysis of variance for grain moisture (%) at Texas environments for LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS[†]	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square WE
Reps	1	0.03	1	0.01	1	0.01	1	0.01	1	2.22	2	3.94*
Hybrids	19	1.11**	19	3.03**	19	6.41**	17	0.85**	12	4.53*	19	4.25**
LAMA TC	14	0.59**	14	1.68**	14	3.47**	13	0.61**	8	3.08	14	3.63**
U.S. Hybrids	4	0.95	4	0.92**	4	1.14	3	0.83**	3	4.04*	4	2.74
LAMA TC*U.S.	1	8.97**	1	27.30**	1	68.71**	1	4.04**	1	17.53**	1	18.88**
Error	19	0.07	21	0.08	19	0.23	17	0.05	12	1.16	38	1.06
Repeatability		0.93		0.97		0.96		0.94		0.74		0.75

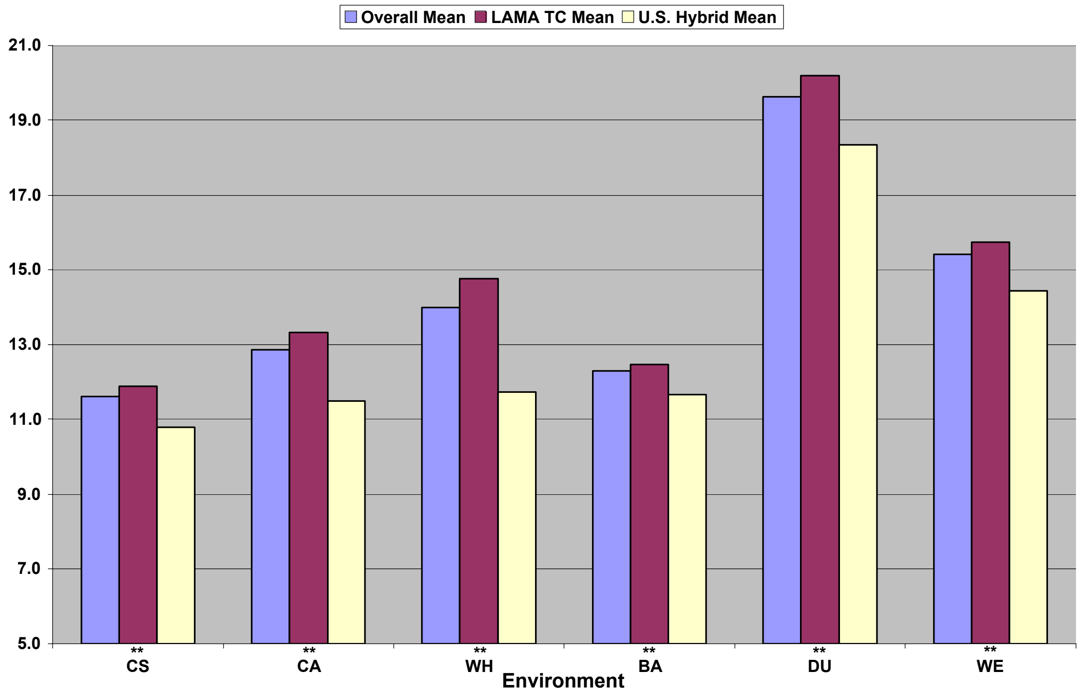
* Significant at P<0.05.
** Significant at P<0.01.
[†] CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.

Environments Dumas and Weslaco had the highest grain moisture percentages, and environments College Station and Bardwell had the lowest grain moisture means (Table 29) (Figure 35). In all environments U.S. hybrids had lower grain moisture means than LAMA testcrosses. Coefficients of variation values were low (most of them less than 5%) in all environments.

Table 29. Grain moisture means (%) for LAMA testcrosses and U.S. hybrids in each environment.

	---%					
	CS†	CA	WH	BA	DU	WE
TX-LAMA2002-2-1-B/LH195	12.15	12.90	14.75	12.66	----	15.83
TX-LAMA2002-5-3-B/LH195	11.80	13.40	13.90	11.79	----	15.00
TX-LAMA2002-6-1-B/LH195	10.85	12.25	13.05	11.69	20.54	13.93
TX-LAMA2002-9-2-B/LH195	10.90	12.20	13.15	11.65	22.11	14.37
TX-LAMA2002-12-1-B/LH195	12.45	14.80	16.30	12.50	----	17.80
TX-LAMA2002-13-B2-B/LH195	11.75	13.45	14.65	12.66	18.64	14.67
TX-LAMA2002-14-B-B/LH195	12.20	13.95	16.30	12.91	22.23	16.50
TX-LAMA2002-17-2-B/LH195	11.45	12.20	14.30	12.30	21.08	16.10
TX-LAMA2002-20-4-B/LH195	12.60	14.70	16.25	13.06	20.18	15.70
TX-LAMA2002-22-2-B/LH195	12.45	14.40	15.60	13.09	19.27	15.77
TX-LAMA2002-25-5-B/LH195	11.65	12.15	12.20	11.74	----	15.77
TX-LAMA2002-42-B-B/LH195	11.80	13.05	14.95	12.65	19.20	14.53
TX-LAMA2002-44-B-B/LH195	11.95	14.15	14.95	----	----	17.50
TX-LAMA2002-46-3-B/LH195	12.55	13.25	16.60	13.29	18.55	16.33
TX-LAMA2002-58-1-B/LH195	11.70	12.95	14.40	12.56	----	16.23
DKC66-80	10.35	11.23	11.40	11.54	16.67	13.33
DKC69-70	12.00	12.65	12.85	12.54	17.66	15.93
P31B13	10.70	11.30	11.15	11.55	19.93	14.07
P32R25	10.40	10.95	11.10	11.00	19.13	14.27
LH195 x LH210	10.50	11.30	12.15	----	----	14.60
Overall Mean	11.61	12.86	14.00	12.29	19.63	15.41
LSD (0.05)‡	0.57**	0.61**	1.00**	0.47**	2.35*	1.76**
C.V., %	2.33	2.27	3.41	1.83	5.49	6.69

* Significant at P<0.05
** Significant at P<0.01
† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.
‡ Fisher's least significant difference, use to compare individual hybrids.



* Significant difference P<0.05 between LAMA TC Mean and U.S. Hybrid Mean.
** Significant difference P<0.01 between LAMA TC Mean and U.S. Hybrid Mean.
CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.

Figure 35. Grain moisture means for all hybrids, LAMA testcrosses, and U.S. hybrids across environments.

Relationship Among Traits

Singular value decomposition biplots were used to illustrate trait correlations in individual environments. In College Station the SVD biplot explained 69% of the variation among traits (Figure 36). The only trait that showed positive correlation with grain yield was plant population. Grain moisture, test weight, and lodging percentage were also positively correlated. In College Station the U.S. hybrids along with LAMA testcross TX-LAMA2002-58-1-B/LH195 were the highest yielders, with TX-

LAMA2002-58-1-B/LH195 yielding higher than three of the U.S. hybrids (Figure 36) (Table 21).

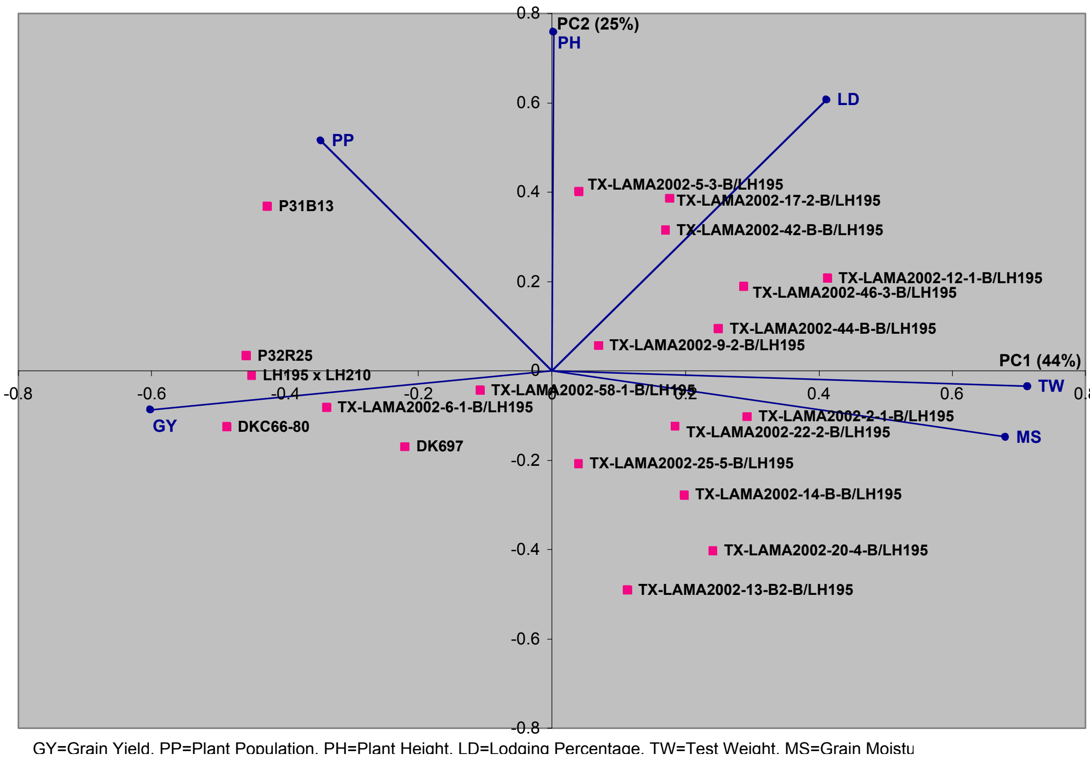


Figure 36. Singular value decomposition biplot for hybrid by trait for LAMA testcrosses and U.S. hybrids at College Station.

In Castroville, the SVD biplot explained 68% of the variation among traits (Figure 37). Plant height showed positive correlation with grain yield, and lodging percentage showed negative correlation with grain yield. Test weight and grain moisture, as well as lodging and plant population also appear to be positively correlated. Hybrids TX-LAMA2002-9-2-B/LH195 and TX-LAMA2002-42-2-B/LH195 were the highest yielding, with several more LAMA testcrosses yielding comparably with U.S. hybrids (Figure 37) (Table 21).

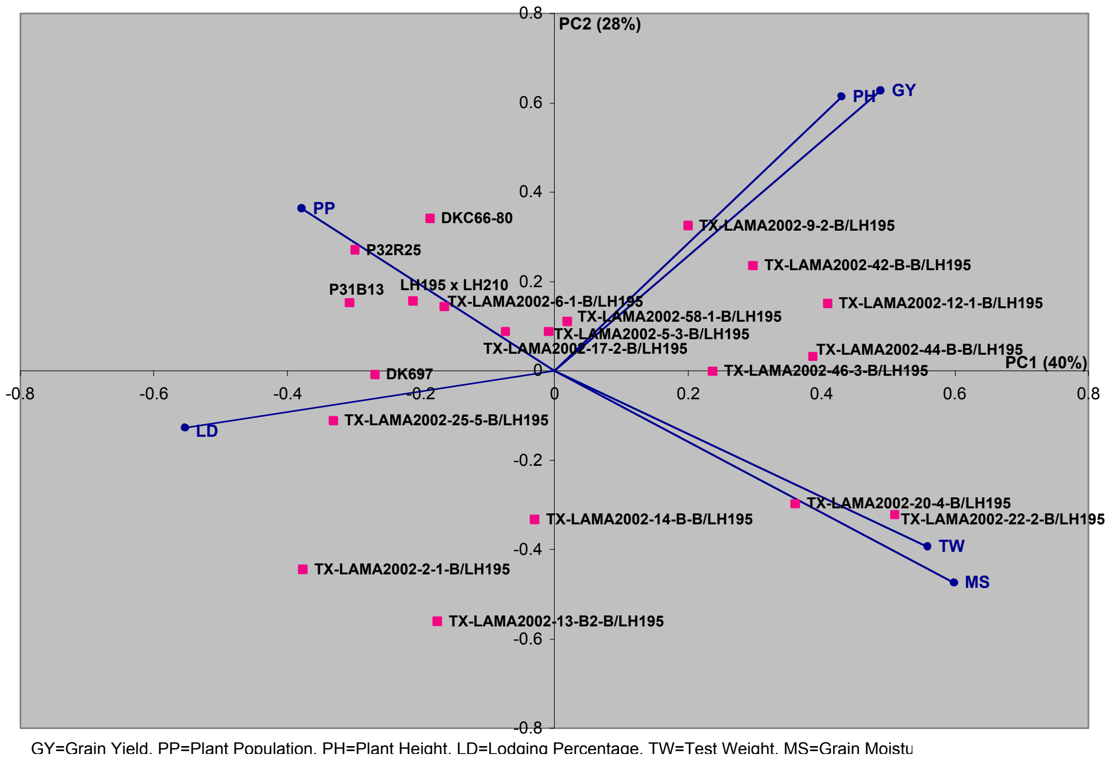


Figure 37. Singular value decomposition biplot for hybrid by trait for LAMA testcrosses and U.S. hybrids at Castroville.

In Wharton, the SVD biplot explained 71% of the variation among traits (Figure 38). Grain yield was not positively correlated with any other trait, but was negatively correlated with grain moisture and test weight. Both lodging percentage and plant height were positively correlated, as well as grain moisture and test weight. Hybrids in Wharton were not significantly different (P<0.05), but four of the U.S hybrids (DKC66-80, DKC69-70, P31B13, and P32R25) and two of the LAMA testcrosses (TX-

LAMA2002-9-2-B/LH195 and TX-LAMA-2002-25-5-B/LH195) had grain yields above 7.5 Mg ha^{-1} (Figure 38) (Table 21).

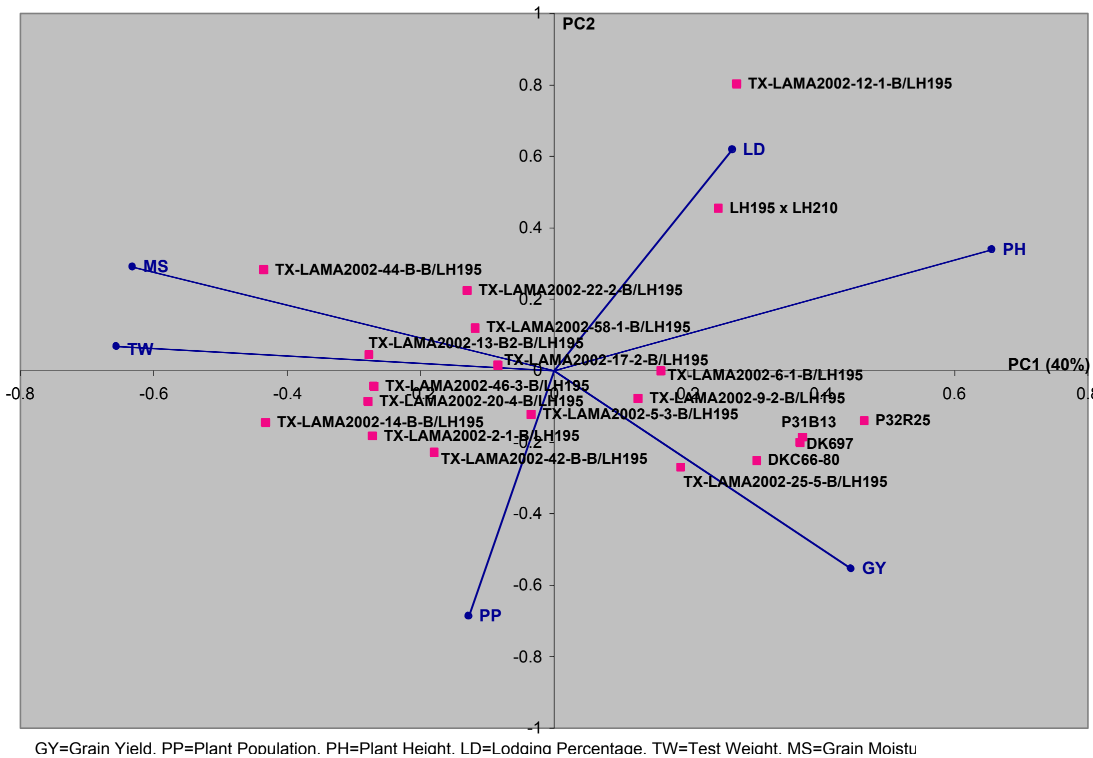


Figure 38. Singular value decomposition biplot for hybrid by trait for LAMA testcrosses and U.S. hybrids at Wharton.

In Bardwell, the SVD biplot explained 63% of the variation among traits (Figure 39). Grain yield was positively correlated with plant population. Grain moisture was positively correlated with test weight, and plant population was positively correlated with plant height, and plant height was positively correlated with lodging percentage. While significant differences ($P<0.05$) for grain yield were not detected in Bardwell either, U.S. hybrid DKC69-70 and LAMA testcrosses TX-LAMA2002-9-2-B/LH195, TX-LAMA2002-12-1-B/LH195, and TX-LAMA2002-14-B-B/LH195 had grain yields greater than 9.0 Mg ha^{-1} (Figure 39) (Table 21).

In Dumas, the SVD biplot explained 57% of the variation among traits (Figure 40). Grain yield was positively correlated with test weight and maybe plant height and grain moisture, but was negatively correlated with lodging percentage. Grain moisture and plant height were positively correlated. U.S. hybrids DKC69-70 and P31B13 and LAMA testcrosses TX-LAMA2002-6-1-B/LH195 and TX-LAMA2002-9-2-B/LH195 were the highest yielding hybrids in Dumas, with grain yields above 11.0 Mg ha^{-1} (Figure 40) (Table 21).

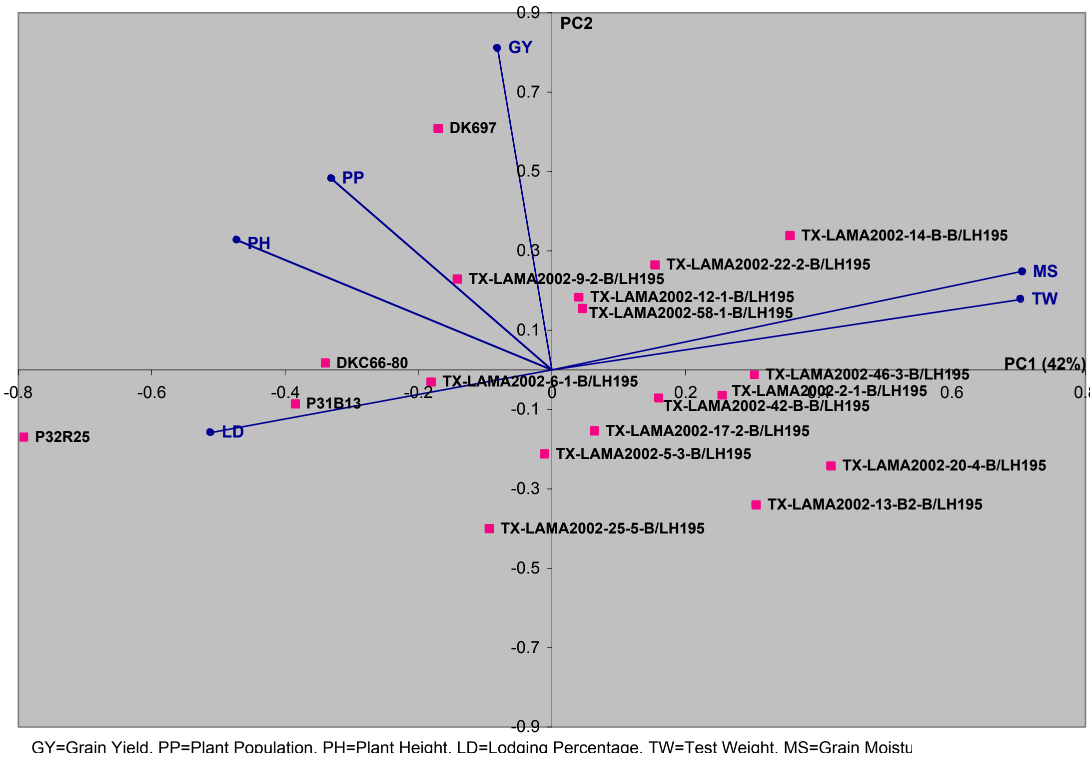


Figure 39. Singular value decomposition biplot for hybrid by trait for LAMA testcrosses and U.S. hybrids at Bardwell.

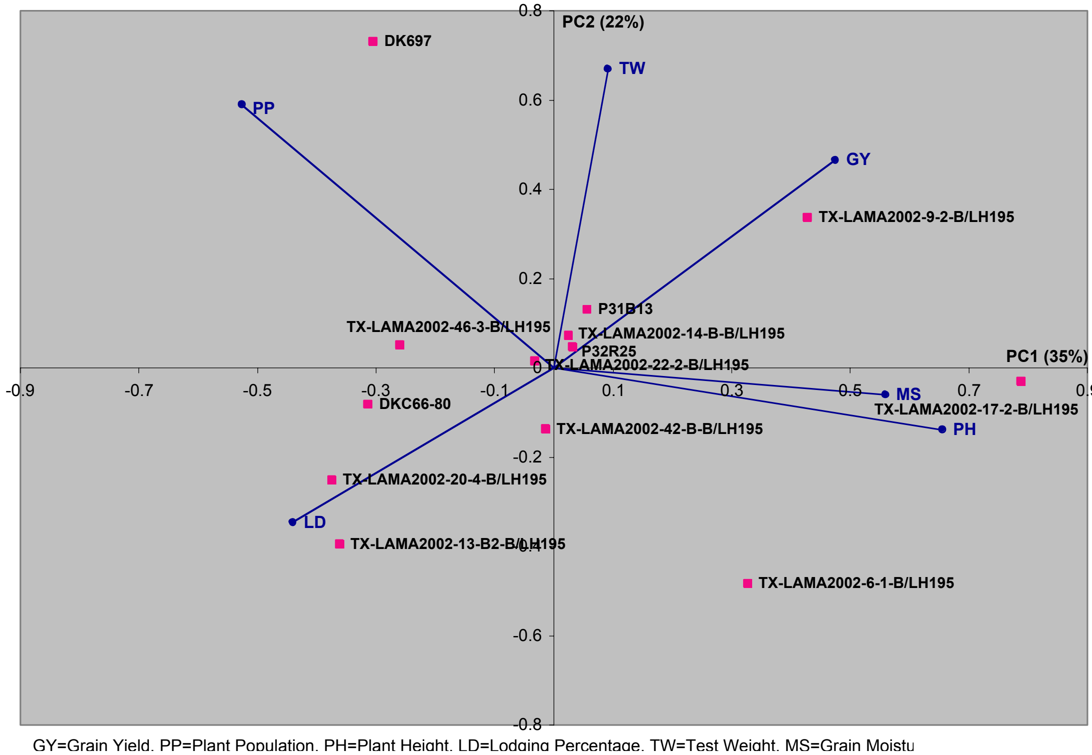


Figure 40. Singular value decomposition biplot for hybrid by trait for LAMA testcrosses and U.S. hybrids at Dumas.

In Weslaco, the SVD biplot explained 64% of the variation among traits (Figure 41). Grain yield was not positively correlated with any traits, and was negatively correlated with both plant population and lodging percentage. Test weight and grain moisture were positively correlated. The highest yielding hybrid was DK69-70 (9.24 Mg ha^{-1}), followed by DKC66-80 (8.29 Mg ha^{-1}) and TX-LAMA2002-12-1-B/LH195 (8.14 Mg ha^{-1}) (Figure 41) (Table 21).

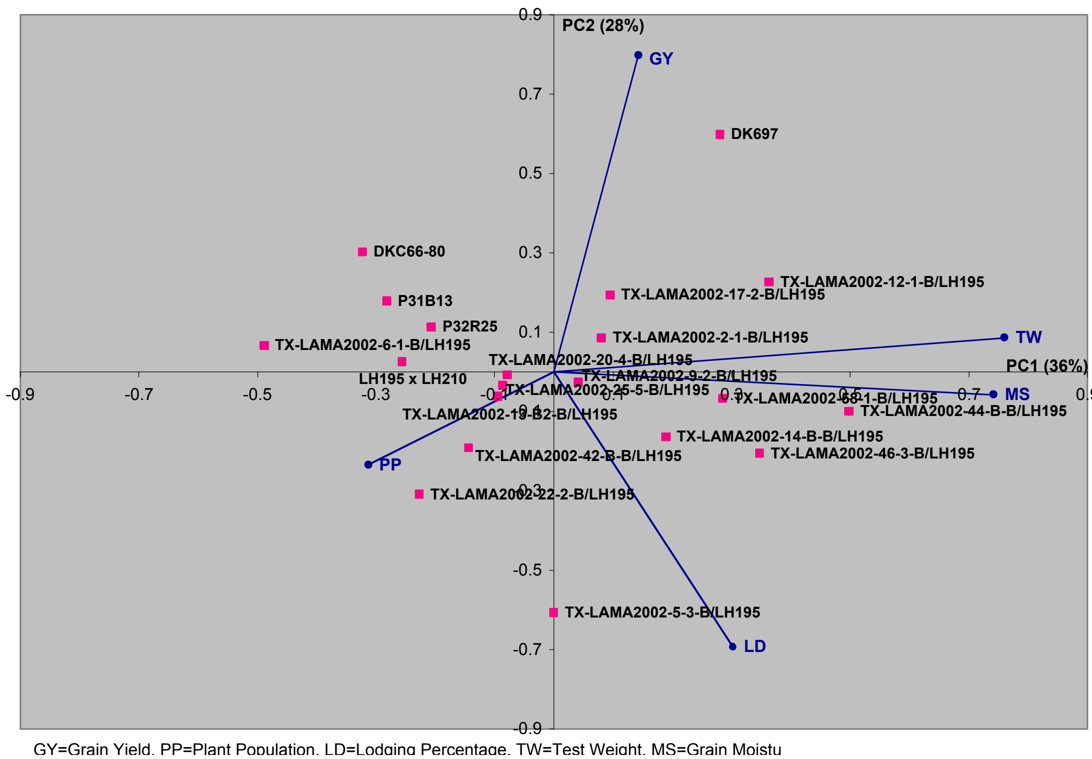


Figure 41. Singular value decomposition biplot for hybrid by trait for LAMA testcrosses and U.S. hybrids at Weslaco.

In Corpus Christi not enough traits were measured to examine trait relationships. There were large differences in grain yield between the U.S. hybrids and LAMA testcrosses with the LAMA testcrosses not being very competitive for grain yield (Table 21).

Across Environment Analysis

ANOVA and Means

For analysis across environments, significant differences (P<0.05) were found among hybrids for all traits (Table 30). All traits except lodging showed significant (P<0.05) differences between LAMA testcrosses and U.S. hybrids. There were also

Table 30. Analysis of variance across environments for grain yield (Mg ha^{-1}), plant population (plants ha^{-1}), test weight (kg hl^{-1}), plant height (cm), lodging (%), and grain moisture (%) for LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square		df	Mean Square	df	Mean Square	df	Mean Square	
		Grain Yield	Plant Population		Test Weight		Plant Height		Lodging Percentage	Grain Moisture
Env	6	48.40**	9298.21**	5	57.36**	6	16591.52**	5	1022.30**	266.24**
Reps(Env)	9	1.27*	13.29	7	0.43	7	181.05*	7	27.76	1.45**
Hybrids	19	3.97**	47.85**	19	15.76**	19	696.73**	19	86.34*	11.54**
LAMA TC	14	2.25**	29.04	14	11.52**	14	897.02**	14	96.40*	5.30**
U.S.	4	2.20*	51.25	4	2.99*	4	125.51	4	24.08	4.56**
LAMA*U.S.	1	35.12**	297.60**	1	126.12**	1	177.58*	1	194.51	126.83**
Env*Hybrid	104	1.38**	29.17**	86	1.63**	105	84.76	86	89.45**	1.43**
Env*LAMA	76	1.32**	26.42*	63	1.07	77	78.98	63	93.96**	1.32**
Env*U.S.	22	1.04	33.39	18	1.55	22	44.14	18	39.14	1.01
Env*LAMA*U.S.	6	3.36**	48.57	5	8.94**	6	307.89**	5	213.67**	4.41**
Error	162	0.57	21.15	124	0.85	126	84.52	126	43.48	0.50
Repeatability		0.86	0.67		0.95		0.94		0.50	0.94

* Significant at P<0.05.
** Significant at P<0.01.

significant interactions ($P<0.05$) between environments and hybrids for all traits except plant height. Repeatabilities ranged from .50 to .94.

Overall means for grain yield, test weight, grain moisture, plant height, lodging percentage, and plant population are reported in Table 31. U.S. hybrids had a higher mean grain yield (9.10 Mg ha^{-1}) than the LAMA testcross mean (8.26 Mg ha^{-1}), and lower grain moisture (13.08%), test weight (75.50 kg hl^{-1}), and lodging percentage (4.27%) than LAMA testcrosses (14.74%, 77.18 kg hl^{-1}, and 6.51% respectively) (Table 31). Coefficients of variation values were low (less than 10%) for all traits except for lodging (109.95%), comparable with single environment analysis.

The top yielding hybrids were U.S. hybrids DKC66-80, DKC69-70, P31B13 and LAMA testcross TX-LAMA2002-9-2-B/LH195, all of which had grain yields greater than 9.0 Mg ha^{-1} across environments (Table 31). TX-LAMA2002-44-B-B/LH195 (79.17 kg hl^{-1}) and TX-LAMA2002-46-3-B/LH195 (78.14 kg hl^{-1}) had the heaviest test

Table 31. Across environment trait means for grain yield (Mg ha^{-1}), test weight (kg hl^{-1}), plant population (plants ha^{-1}), lodging (%), plant height (cm), and grain moisture (%) for LAMA testcrosses and U.S. hybrids.

	Grain Yield	Test Weight	Plant Population	Lodging Percent	Plant Height	Grain Moisture
TX-LAMA2002-2-1-B/LH195	8.16	77.65	68.79	8.44	239.70	14.74
TX-LAMA2002-5-3-B/LH195	8.32	76.15	69.17	14.59	248.83	14.26
TX-LAMA2002-6-1-B/LH195	8.76	75.08	66.81	3.69	254.67	13.67
TX-LAMA2002-9-2-B/LH195	9.01	77.83	66.91	7.90	259.91	14.05
TX-LAMA2002-12-1-B/LH195	8.40	76.95	64.75	8.56	266.93	15.88
TX-LAMA2002-13-B2-B/LH195	7.41	76.94	65.27	6.54	238.73	14.29
TX-LAMA2002-14-B-B/LH195	8.20	77.87	68.25	2.99	234.37	15.64
TX-LAMA2002-17-2-B/LH195	8.49	76.77	66.96	7.00	256.18	14.53
TX-LAMA2002-20-4-B/LH195	8.19	77.40	66.49	2.94	238.05	15.37
TX-LAMA2002-22-2-B/LH195	8.21	76.87	67.05	3.76	250.70	15.17
TX-LAMA2002-25-5-B/LH195	8.23	75.60	65.59	7.13	246.70	13.81
TX-LAMA2002-42-B-B/LH195	8.43	77.38	68.86	6.89	251.54	14.38
TX-LAMA2002-44-B-B/LH195	7.98	79.17	68.36	6.07	250.68	15.52
TX-LAMA2002-46-3-B/LH195	8.04	78.14	67.69	7.19	255.84	15.15
TX-LAMA2002-58-1-B/LH195	8.03	77.82	68.72	4.02	249.70	14.67
DKC66-80	9.13	75.16	69.92	2.82	248.69	12.42
DKC69-70	9.63	76.35	71.50	5.40	251.21	14.03
P31B13	9.29	75.64	69.89	5.09	254.21	13.10
P32R25	8.85	75.13	68.93	5.40	256.85	12.83
LH195 x LH210	8.62	75.21	66.43	2.65	253.42	13.01
Overall Mean	8.47	76.76	67.82	5.95	250.35	14.33
LAMA Testcross Mean	8.26	77.18	67.31	6.51	249.50	14.74
U.S. Hybrid Mean	9.10	75.50	69.33	4.27	252.88	13.08
LSD (0.05)†	0.82**	0.99**	3.91**	7.37*	7.16**	0.93**
C.V., %	9.05	1.20	6.68	109.95	3.69	5.01

* Significant at P<0.05
** Significant at P<0.01
† Fisher's least significant difference, use to compare individual hybrids.

weight means across environments and several of the LAMA testcrosses had test weight means over 77.00 kg hl^{-1}. U.S. hybrids LH195 x LH210 (2.65%) and DKC66-80 (2.82%) had the lowest means for lodging, but LAMA testcrosses LAMA2002-20-4-B/LH195 (2.94%) and TX-LAMA2002-14-B-B/LH195 (2.99%) were also competitive. For grain moisture, all U.S. hybrids except DKC69-70 (14.03%) were below 14% moisture, and the LAMA testcrosses with the lowest grain moisture, TX-LAMA2002-6-1-B/LH195 (13.67%) and TX-LAMA2002-25-5-B/LH195 (13.81%) were comparable to U.S. hybrids (Table 31).

Relationship Among Traits

The SVD biplot of hybrid by trait illustrated correlations between different yield components and other agronomic traits across environments (Figure 42). This SVD biplot explained 64% of the variation for the two-way table hybrid by trait across environments. Grain yield was positively correlated with plant population, and negatively correlated with grain moisture and test weight. Test weight and grain moisture were positively correlated. Plant height and lodging percentage appeared to be positively correlated (Figure 42).

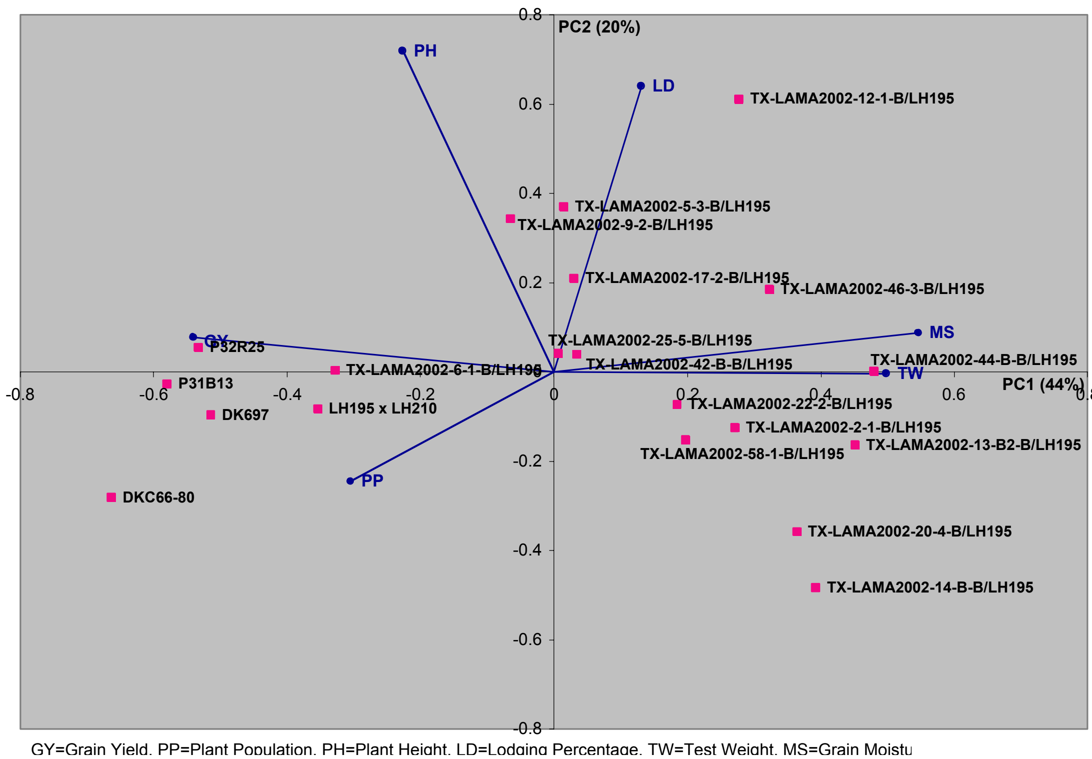


Figure 42. Singular value decomposition biplot for across environment hybrid by trait for LAMA testcrosses and U.S. hybrids.

Stability Analysis

Regression stability parameters for grain yield, test weight, plant height, lodging percentage, and grain moisture are reported in Table 32. For grain yield the range in slopes was from .44 to 1.51, -.01 to 1.57 for test weight, .55 to 1.42 for plant height, .75 to 1.39 for grain moisture, and .22 to 2.04 for lodging percentage (Table 32).

Table 32. Regression stability parameters for LAMA testcrosses and U.S. hybrids across environments in Texas.

	Grain Yield		Test Weight		Plant Height		Grain Moisture		Plant Lodging	
	Slope	Sum of Residual^2	Slope	Sum of Residual^2	Slope	Sum of Residual^2	Slope	Sum of Residual^2	Slope	Sum of Residual^2
TX-LAMA2002-2-1-B/LH195	0.58	3.58	0.55	1.23	1.04	179.17	1.03	0.21	1.90	19.46
TX-LAMA2002-5-3-B/LH195	1.07	2.09	0.96	1.42	1.05	63.86	0.88	0.69	1.76	364.72
TX-LAMA2002-6-1-B/LH195	1.26	1.60	1.00	2.30	1.15	247.47	1.14	1.65	0.64	115.65
TX-LAMA2002-9-2-B/LH195	1.27	3.61	0.90	0.95	0.95	73.15	1.38	2.71	1.48	26.15
TX-LAMA2002-12-1-B/LH195	0.74	2.25	1.50	1.82	0.96	116.86	1.51	1.44	0.65	455.59
TX-LAMA2002-13-B2-B/LH195	0.54	4.47	1.42	1.70	1.04	398.04	0.81	0.92	1.32	265.56
TX-LAMA2002-14-B-B/LH195	1.32	1.68	1.29	0.56	1.19	266.41	1.19	1.44	0.43	9.06
TX-LAMA2002-17-2-B/LH195	1.05	1.96	0.79	1.04	1.20	197.64	1.18	0.42	2.04	549.49
TX-LAMA2002-20-4-B/LH195	0.75	1.62	1.57	0.86	0.91	249.63	0.87	2.64	0.22	19.11
TX-LAMA2002-22-2-B/LH195	1.09	0.85	1.51	3.78	0.97	244.67	0.86	1.17	0.37	28.36
TX-LAMA2002-25-5-B/LH195	0.98	1.07	1.18	0.74	1.22	51.72	1.01	2.73	1.51	46.56
TX-LAMA2002-42-B-B/LH195	0.82	1.67	1.51	1.75	1.16	373.80	0.90	1.49	1.28	58.38
TX-LAMA2002-44-B-B/LH195	0.85	2.21	0.70	0.09	0.55	303.60	1.39	0.43	0.52	26.24
TX-LAMA2002-46-3-B/LH195	0.44	2.99	1.04	1.68	0.83	160.95	0.79	4.02	0.85	179.88
TX-LAMA2002-58-1-B/LH195	1.51	5.48	-0.01	0.26	1.00	118.29	1.18	0.03	0.48	78.64
DKC66-80	0.75	1.46	0.49	0.98	1.00	117.02	0.75	1.07	0.31	36.57
DKC69-70	1.26	3.32	1.03	14.72	0.81	205.83	0.80	2.02	1.50	284.37
P31B13	1.19	4.42	1.00	1.37	0.80	242.71	1.15	4.07	1.39	63.07
P32R25	1.00	2.37	0.23	3.87	0.94	225.85	1.13	2.65	0.79	144.52
LH195 x LH210	1.40	2.33	0.48	0.60	1.42	112.82	1.05	0.59	0.45	60.21

For grain yield, several of the LAMA testcrosses appeared to be the more stable across environments than the U.S. hybrids although the LAMA testcrosses did yield less (Figure 43) (Table 32). LAMA testcrosses TX-LAMA2002-25-5-B/LH195, TX-LAMA2002-17-2-B/LH195, TX-LAMA2002-5-3-B/LH195, and TX-LAMA2002-22-2-B/LH195 along with U.S. hybrid P32R25 (the second lowest yielding U.S. hybrid across environments) had slopes closest to 1 for grain yield.

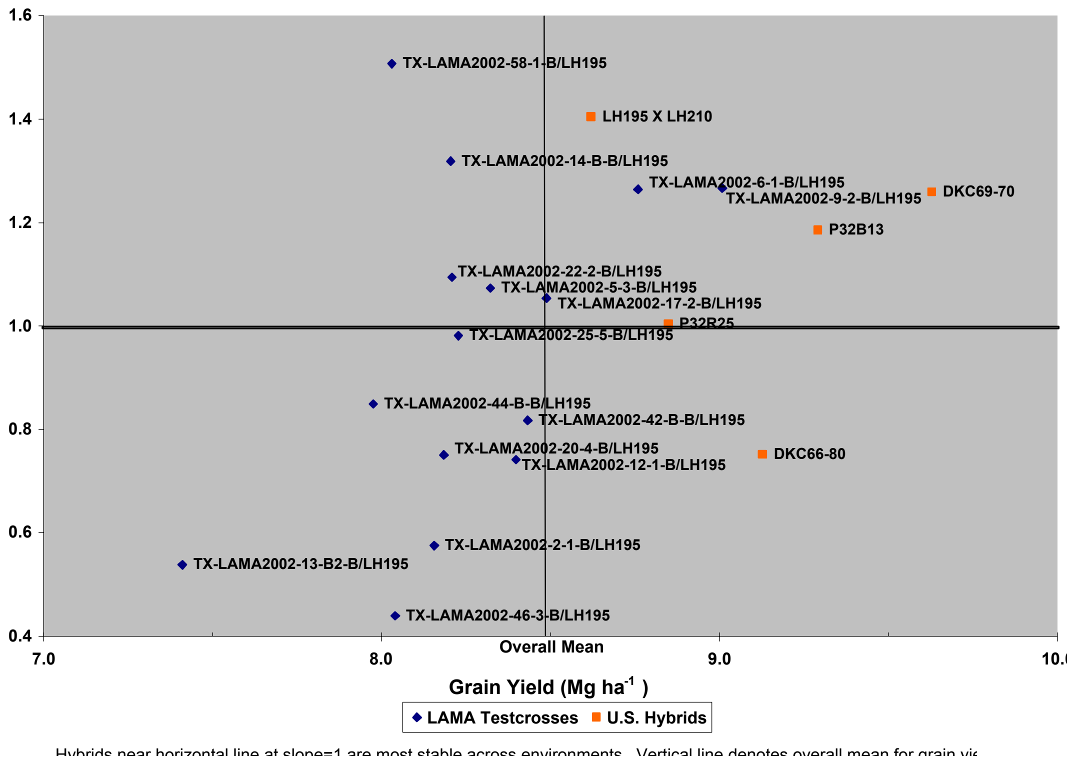


Figure 43. Grain yield vs. regression slope for LAMA testcrosses and U.S. hybrids across Texas environments.

For test weight, many of the LAMA testcrosses had slopes near 1, as did U.S. hybrids P31B13 and DKC69-70 (Figure 44). Several of the more stable LAMA testcrosses had some of the higher test weight means, and most LAMA testcrosses had test weights above the overall mean (Figure 44). DKC66-80, LH195 x LH210, and P32R25 had some of the lowest test weights and showed less stability across environments for test weight (Figure 44) (Table 32).

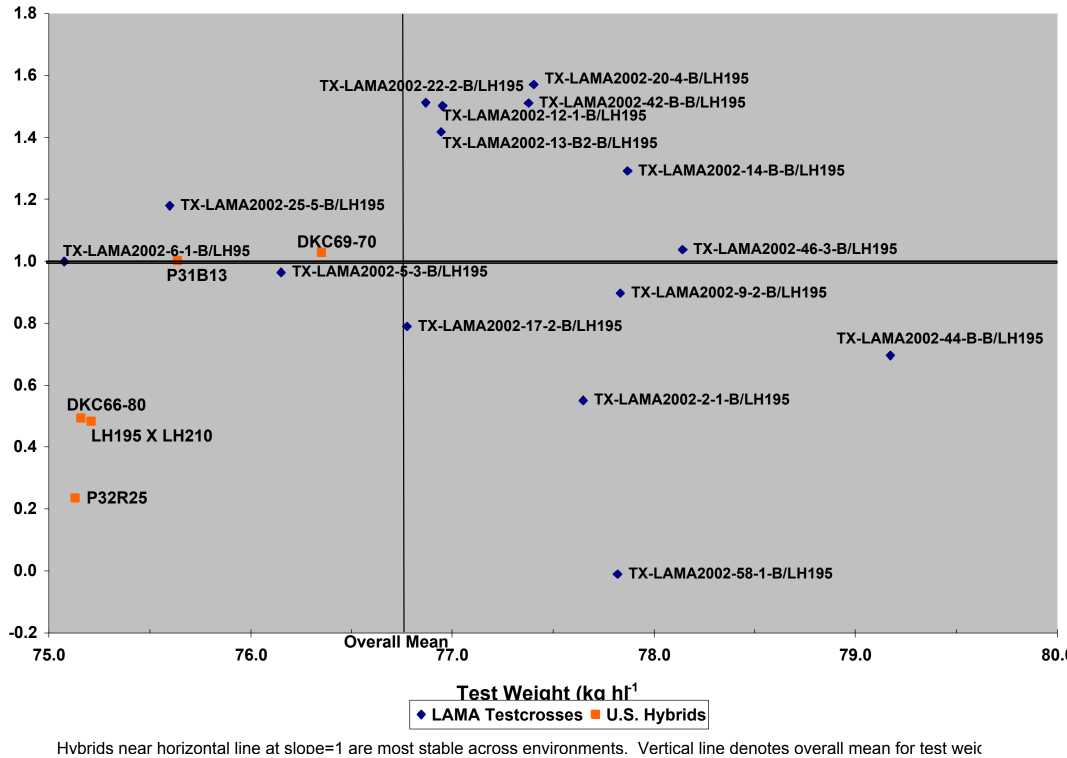


Figure 44. Test weight vs. regression slope for LAMA testcrosses and U.S. hybrids across Texas environments.

For grain moisture, the U.S. hybrids had lower grain moisture at harvest than LAMA testcrosses. Most of the LAMA testcrosses had grain moistures above the overall mean (Figure 45). Approximately ten of the LAMA testcrosses were as stable as or more stable for grain moisture than the U.S. hybrids. Both TX-LAMA2002-6-1-B/LH195 and TX-LAMA2002-25-5-B/LH195 had grain moisture less than the overall mean and slopes near 1 comparable with several of the U.S. hybrids (Figure 45).

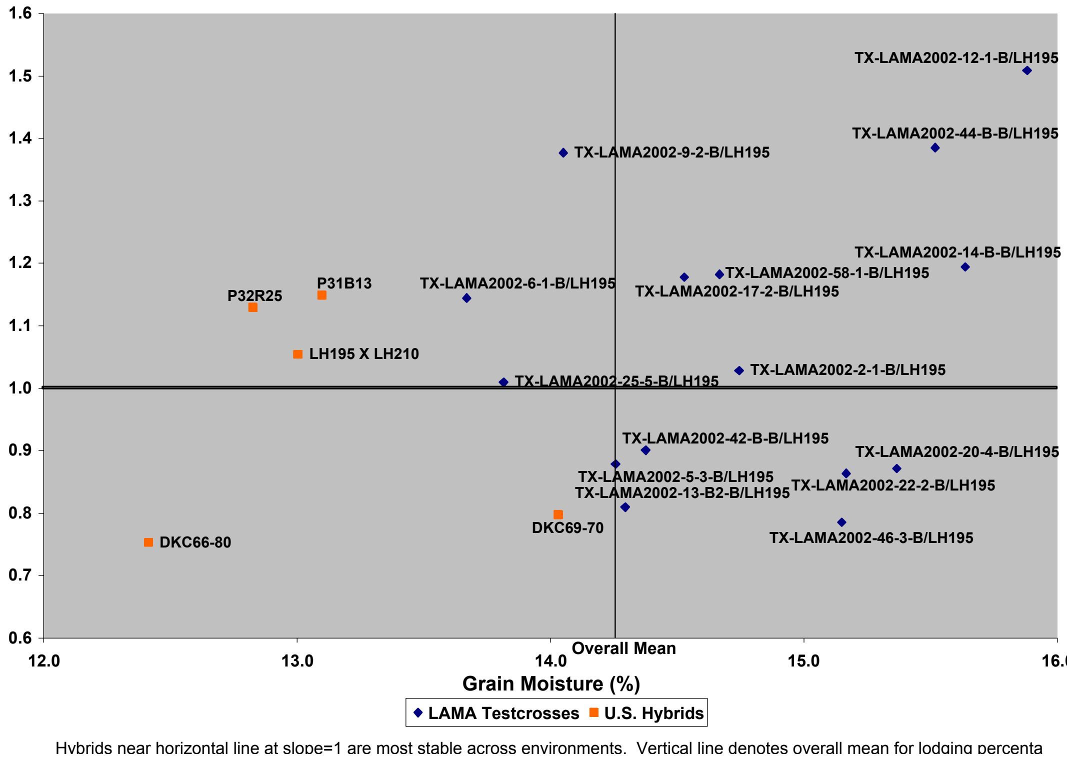
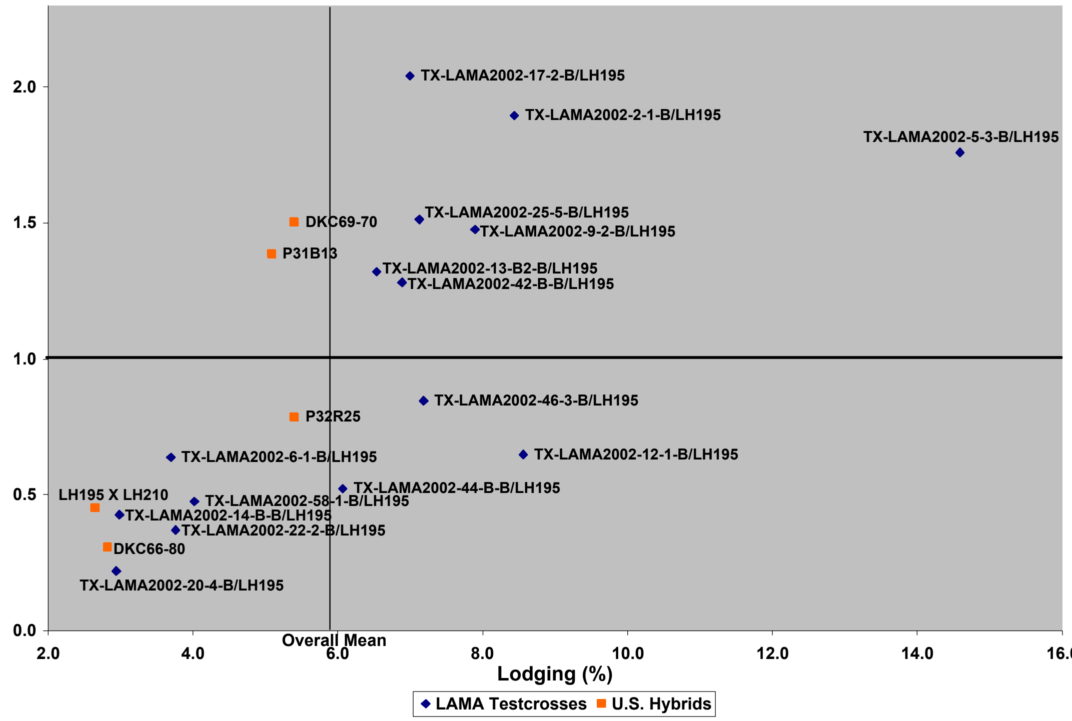


Figure 45. Grain moisture vs. regression slope for LAMA testcrosses and U.S. hybrids across Texas environments.

For lodging percentage, all five U.S. hybrids and about five of the LAMA testcrosses had mean lodging less than the overall mean (Figure 46). Approximately 12 of the LAMA testcrosses had stability across environments for lodging comparable to U.S hybrids. TX-LAMA2002-6-1-B/LH195 had low incidence of lodging (less lodging than three U.S. hybrids) and one of the slopes nearest to 1 among the hybrids (Figure 46).



Hybrids near horizontal line at slope=1 are most stable across environments. Vertical line denotes overall mean for lodging percentage.

Figure 46. Lodging percentage vs. regression slope for LAMA testcrosses and U.S. hybrids across Texas environments.

For plant height, the LAMA testcrosses had a larger range in heights having both the shortest plants and the tallest plants across environments (Figure 47). Although there were some fairly unstable materials in both groups (slopes not near 1) many of the hybrids tested had slopes really close to 1 (.90 to 1.10). LAMA testcrosses TX-LAMA2002-5-3-B/LH195, TX-LAMA2002-22-2-B/LH195, and TX-LAMA2002-58-1-B/LH195 all had slopes very near 1 (most stable) and plant heights that were comparable to U.S. hybrids (Figure 47).

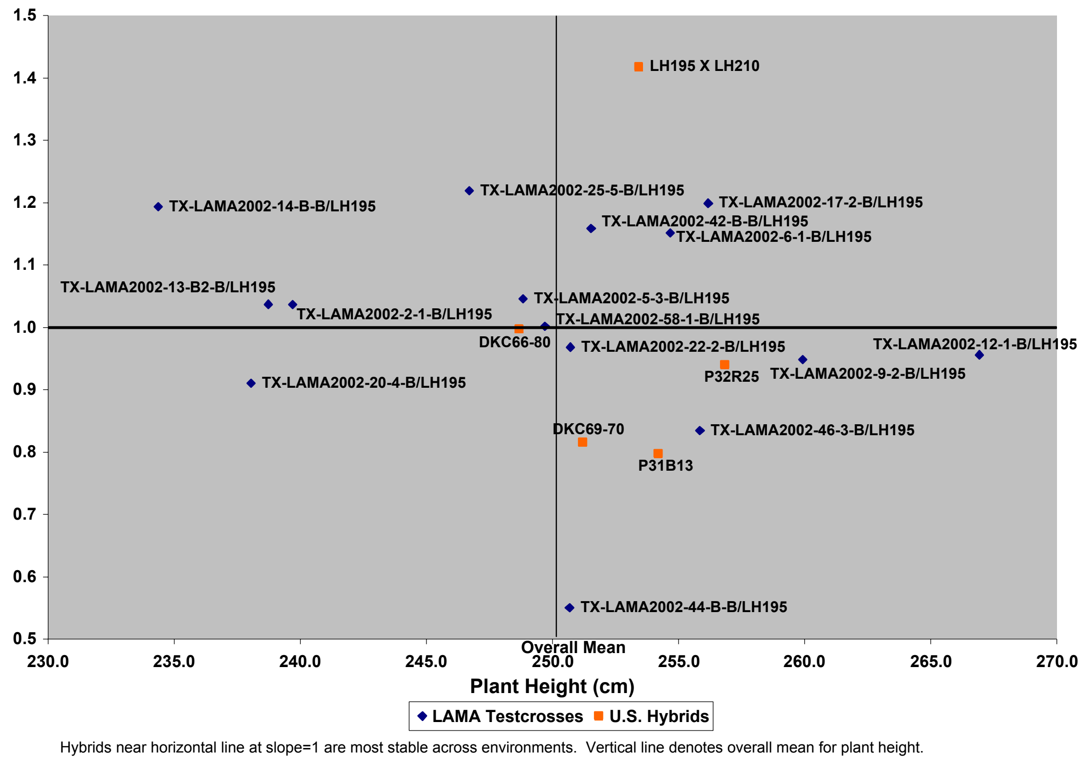


Figure 47. Plant height vs. regression slope for LAMA testcrosses and U.S. hybrids across Texas environments.

Discussion and Conclusions

For grain yield there was a large difference between environments with almost 3 Mg ha^{-1} difference between College Station and Wharton, the highest and lowest yielding environments, respectively. In College Station and Castroville, the LAMA testcrosses were very competitive with U.S. hybrids, and eight LAMA testcrosses in College Station and ten LAMA testcrosses in Castroville were not significantly different from the highest yielding hybrid.

The highest yielding hybrid was TX-LAMA2002-58-1-B/LH195 in College Station, TX-LAMA2002-9-2-B/LH195 in Castroville, TX-LAMA2002-25-5-B/LH195 in Wharton, and TX-LAMA2002-14-4-B/LH195 in Bardwell. Across environments, U.S. hybrids had higher grain yield means, but TX-LAMA2002-9-2-B/LH195 had grain yield mean above 9.0 Mg ha^{-1}, and was better yielding than two of the U.S. hybrids. Several of the LAMA testcrosses were among the top yielders in two to three environments each. They seem especially well suited for the College Station and Castroville regions.

Test weights among LAMA testcrosses were much heavier than test weights for U.S. hybrids. In each individual environment, the heaviest test weight mean was for a LAMA testcross, and TX-LAMA2002-44-B-B/lH195 had the heaviest test weight mean in three environments and the heaviest mean overall. Eight different LAMA testcrosses were not significantly different from the heaviest test weight mean entry overall, but all the U.S. hybrids were significantly lower. Bardwell, Castroville, and College Station were the best environments for LAMA testcross test weight means, as nine, eight, and seven, respectively. LAMA testcrosses did not differ from the entry with the highest test weights. In addition to showing the heaviest test weights, the LAMA testcrosses also had a wider range in test weights, which means more variability for selection during breeding

Plant lodging only seemed problematic in College Station and Castroville, where over 10% of the plants were lodged. Individual hybrids may have had lodging problems in other environments, but the majority of hybrids had low incidence of lodging elsewhere. There were not significant differences between the LAMA testcrosses and U.S. hybrids for lodging percentage. Overall, TX-LAMA2002-5-3-B/LH195 had the highest lodging mean (14.59%). It appears that selection for lodging during line development helped to solve one of the problems usually associated with using exotic germplasm.

LAMA testcrosses had significantly lower plant heights than the U.S. hybrids. While plant height and lodging were thought to be positively correlated, some LAMA testcrosses with shorter plant height means actually had the highest incidence of lodging, and the U.S. hybrids had taller plant heights, but lower incidence of lodging.

U.S. hybrids had lower grain moisture percentage means than the LAMA testcrosses, but several of the LAMA testcrosses were competitive, with six LAMA testcrosses having grain moisture below 14.5%. So again selection during line development of the LAMA testcrosses showed success for lowering grain moisture, another problem associated with using exotic germplasm in U.S. breeding programs.

Stability across environments was quite variable for both U.S. hybrids and LAMA testcrosses for different traits. For grain yield, test weight, grain moisture, lodging, and plant height some of the LAMA testcrosses were the most stable (slopes near 1) and also the least stable. Traits such as lodging and test weight showed the most diverse stability values for LAMA testcrosses.

TX-LAMA2002-9-2-B/LH195 was one of the highest yielding entries, had one of the heaviest test weights, and lower grain moisture. While it had a lodging mean of 7.90%, it was not significantly different than the lowest lodging percentage entry, and also appeared quite stable across environments for several traits. Several other LAMA testcrosses had competitive grain yield and heavy test weights, with low incidence of lodging and lower grain moistures.

In this experiment grain yield was positively correlated with plant population and negatively correlated with grain moisture and test weight. Test weight and grain moisture appear positively correlated, as does lodging and plant height.

These testcrosses need to be evaluated in more environments and possibly the Corn Belt, to determine their true performance when compared with U.S. commercial hybrids. In addition a few more cycles of selection for the exotic lines and testcross evaluation with other inbred lines would also help determine their value. Overall they appear to be promising for use in breeding program, especially to increase test weight in U.S. temperate maize.

With more selection for grain yield, valuable inbred lines could be developed from the 100% tropical materials and used to form elite hybrids with temperate inbreds, or possibly other 100% tropical, elite inbreds. These hybrids could be very competitive yielders with current commercial hybrids and possess heavier test weights and possible resistance to diseases and insects. By maintaining selection pressure for grain moisture, standability, and grain yield these materials could be improved further and be readily useable by different maize breeding programs for sources of new alleles.

CHAPTER V

AFLATOXIN EVALUATION

Introduction

Aflatoxin Research

Aflatoxin contamination of maize grain, as well as other crops such as peanut, cotton, and others, was recognized as a problem and health risk to both humans and livestock in the middle of the 20^{th} century (Anderson et al., 1975; Castegnaro and McGregor, 1998; Cleveland et al., 2003; Munkvold, 2003). Many different control methods have been proposed and researched, but resistance to preharvest grain contamination of maize is the most promising method (Darrah et al., 1987). There are several reasons why aflatoxin resistance is difficult to breed for in maize, including the cost of testing, difficulty in repeating results due to environment by genotype interaction, as well as present inoculation methods that do not always produce enough contamination to distinguish between genotypes (Darrah et al., 1987; Widstrom et al., 1984; Widstrom et al., 1987; Widstrom et al., 1978).

Exotic Maize and Mycotoxins

Using exotic maize as source of novel alleles for mycotoxin resistance has been proposed due to the biotic and abiotic stress tolerance of these materials, although agronomic acceptance and adaptation may limit their use (Betrán et al., 2002). High aflatoxin levels are favored by plants that are stressed by lack of water or soil fertility, damage from insects or animals, high temperatures, weed pressure, and agronomic practices, and while many of these parameters can be reduced through cultural production practices, not all can be eliminated or dealt with easily (Moreno and Kang, 1999; Munkvold, 2003).

The purpose of this experiment was to determine if exotic materials that possessed traits such as earliness, foliar disease resistance, tight husk coverage, and tolerance of abiotic stresses might be used to reduce preharvest aflatoxin contamination of grain. Therefore both sets of exotic materials previously introduced were screened for aflatoxin response in 2004.

Materials and Methods

Inoculation Techniques

Aspergillus flavus inoculation methods can either cause injury to the kernels or be of the non-wounding nature, with a non-wounding method usually preferred as it does not defeat resistance due to the outer coverings of the kernel (Darrah et al., 1987; Zummo and Scott, 1989). We used two methods of inoculation in these experiments: the non-wounding silk channel inoculation technique where ears are inoculated through the silk channel 6-10 days after silking with 3 ml of the conidial suspension (~10^7 / ml) with a syringe, and the colonized kernel technique where colonized autoclaved maize kernels are placed on the soil surface between treatment rows when the first hybrids reach mid-silk stage (Zummo and Scott, 1989). For these experiments we used the non-wounding silk channel inoculation method in Weslaco and College Station, and the colonized kernel ground inoculation method in Corpus Christi.

Field Evaluation

The Argentine hybrids and U.S. commercial hybrids from the previous experiment were also grown in three environments for aflatoxin screening. For the LAMA testcrosses, a larger set of testcrosses (29 testcrosses) and two more U.S. hybrids (6 total) were available for aflatoxin screening across the three environments than for agronomic testing. The data presented below is for the complete set of LAMA testcrosses evaluated in the aflatoxin trials. Both sets of material, Argentine hybrids and LAMA testcrosses, were tested in separate experiments.

Three southern Texas environments were used for evaluation of aflatoxin under inoculation in 2004, Weslaco, Corpus Christi, and College Station. In each environment experimental units were one row plots. Field experimental design was alpha lattice with three replicates. Drought stress was induced by limited irrigation and late planting dates. Both experiments were inoculated in the same fashion.

In Weslaco and College Station, five plants per plot were tagged with ribbons after pollination and then inoculated through the silk channel with a conidial suspension of *A. flavus*. Other traits measured (and presented earlier in thesis) were grain yield, test weight, grain moisture, plant height, and lodging percentage. For the Argentine hybrids, 1000 kernel weights were also taken. In Corpus Christi, whole plots were inoculated with *A. flavus* colonized kernels placed on the ground in between plots.

Aflatoxin Quantification

At harvest in Weslaco and College Station, the ears from tagged plants were harvested by hand, shelled, and then bulked. In Corpus Christ all ears from a plot were harvested, shelled, and bulked. These plot samples were then ground using a Romer mill (Romer Labs, Union, MO), and aflatoxin was quantified from 50-g subsamples using the VICAM Aflatest® (VICAM, Watertown, MA).

Statistical Analysis

For analysis of variance both in single environments and across environments, aflatoxin concentration data was transformed using the base 10 logarithm in order to equalize variances. Analysis of variance was done using Proc GLM in SAS (SAS Institute, 2002). Means for hybrids were estimated using the geometric (or antilogarithmic) means from the Proc Mixed procedure in SAS 9.0. Data was then combined across environments, and overall means were determined using Proc Mixed in SAS, considering entries as fixed effects and environments as random effects. Overall means were used to determine trait correlation using SVD for the Argentine hybrids.

Results

Argentine Hybrids

Single Environment Analysis

In the three environments used for inoculation with *A. flavus*, reps were not significant ($P<0.05$) in any environment, which is somewhat surprising since aflatoxin accumulation in preharvest maize usually shows great amounts of field variation (

Table 33. ANOVA table and repeatabilities for base 10 logarithmic aflatoxin at Texas environments for Argentine and U.S. hybrids.

Source	df	Mean Square		
		CS[†‡]	WE	CC
Reps	2	0.91	0.01	0.10
Hybrids	19	0.47	0.55**	0.71**
Argentine	14	0.40	0.57**	0.89**
U.S.	4	0.42*	0.05	0.24
Argentine*U.S.	1	1.58*	1.64**	0.19
Error	38	0.34	0.17	0.26
Repeatability		0.28	0.70	0.64

* Significant at P<0.05
** Significant at P<0.01
[†] Location abbreviations are CS=College Station, WE=Weslaco, and CC=Corpus Christi.
[‡] Due to a missing entry, College Station degrees of freedom for Hybrids=18, U.S.=3, and Error=34.

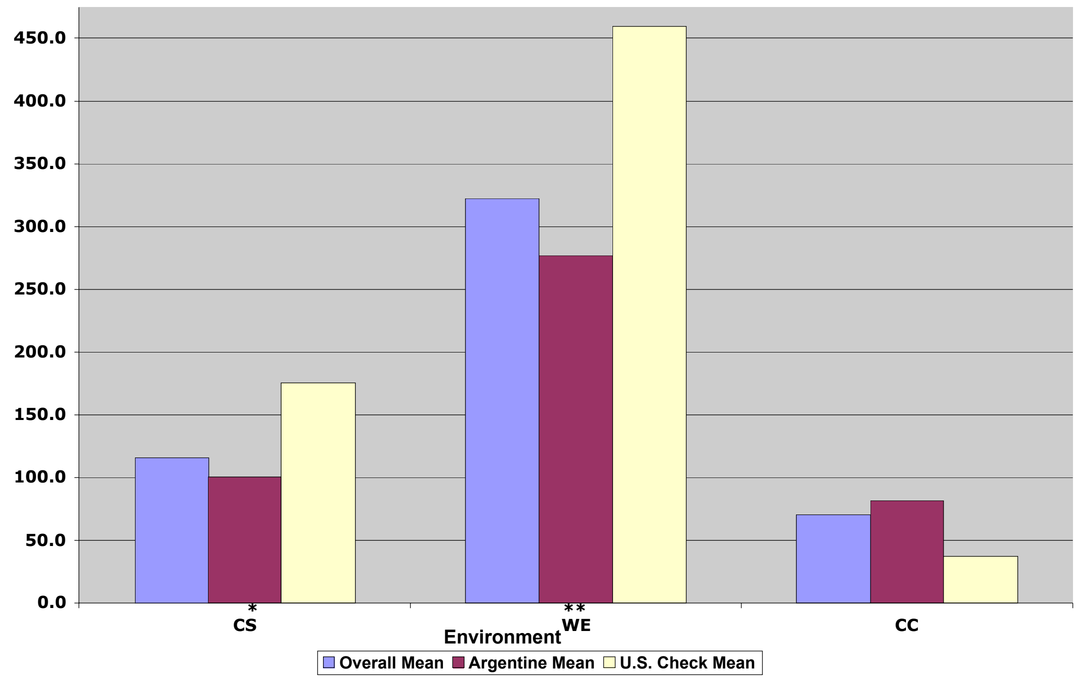
Table 33). Statistical differences ($P<0.05$) among individual hybrids were detected in Weslaco and Corpus Christi, and statistical differences ($P<0.05$) between the Argentine and U.S. hybrids were detected in College Station and Weslaco. Repeatabilities were .28 in College Station, .70 in Weslaco, and .64 in Corpus Christi; these estimates suggest that the two south Texas environments were better environments to display genotypic differences among hybrids for aflatoxin contamination.

Weslaco had the highest overall mean aflatoxin levels, followed by College Station and Corpus Christi (Table 34). Corpus Christi had noticeably lower aflatoxin concentrations than in previous years evaluations. This was probably due to heavy rains around flowering and post-flowering time that preclude a favorable environment for aflatoxin production. In College Station (CS) and Weslaco (WE), Argentine hybrids overall had less aflatoxin contamination in grain, but in Corpus Christi (CC) the U.S. hybrids had less aflatoxin contamination (Table 34) (Figure 48). Coefficients of variation were relatively high and ranged from 17.62 to 31.64%.

Table 34. Mean antilogarithmic aflatoxin (ng g^{-1}) at Texas environments for Argentine and U.S. hybrids.

	ng g^{-1}		
	College Station†	Weslaco	Corpus Christi
A933	53.60	321.29^{bcdef}	36.14^{cdefg}
AX877	156.57	1417.42^{a}	250.55^{ab}
AX878	38.72	53.63^{fgh}	95.26^{abcd}
AX882	20.99	427.46^{abc}	294.37^{a}
AX884IT	46.57	86.00^{defgh}	187.85^{abc}
AX888IT	23.30	88.45^{defgh}	30.24^{cdefg}
AX889	66.65	20.00^{h}	5.70^{fg}
AX934	447.71	392.55^{abcde}	115.61^{abcd}
AX956	138.07	352.61^{abcde}	57.86^{abcde}
AX882MG	101.98	158.96^{cdefgh}	69.15^{abcde}
AX890MG	64.42	266.50^{bcdefgh}	17.11^{defg}
DK682	154.92	238.01^{bcdef}	25.98^{cdefg}
CONDOR	50.16	84.64^{efgh}	4.98^{g}
NK900TDMAX	104.28	39.64^{gh}	22.55^{defg}
AGRI124	44.58	208.79^{bcdef}	15.13^{efg}
DKC66-80	53.70	537.03^{abcd}	83.98^{abcde}
DKC69-70	84.74	605.20^{ab}	19.77^{defg}
P31B13	409.54	492.61^{abcde}	20.01^{defg}
P32R25	153.53	359.25^{bcde}	23.60^{cdefg}
W4700	----	302.55^{bcde}	40.19^{bcdef}
Overall Mean	116.53	322.63	70.80
C.V., %	30.61	17.62	31.64

† Hybrids followed by the same letter are not significantly different from each other at the 0.05 level (LSD).



* Significant difference at P<0.05 between Argentine and U.S. hybrid
** Significant difference at P<0.01 between Argentine and U.S. hybrids.
CS=College Station, WE=Weslaco, and CC=Corpus Christi

Figure 48. Antilogarithmic aflatoxin means for all hybrids, Argentine and U.S. hybrids across environments.

Across Environment Analysis

Across environments there was a significant difference (P<0.05) among environments (Table 35). Significant differences (P<0.05) were also found among hybrids and between Argentine and U.S. hybrids. For the logarithmic transformation of aflatoxin there was also significant interaction (P<0.05) between hybrids and environments (Table 35). Repeatability was .54 across environments.

Table 35. Analysis of variance for base 10 logarithm of aflatoxin concentration (ng g^{-1}) across environments for Argentine and U.S. hybrids.

Source	df	Mean Square
Env	2	7.47**
Reps(Env)	6	0.34
Hybrids	19	0.86**
Argentine	14	1.03**
U.S.	4	0.06
Argentine*U.S.	1	1.43*
Env*Hybrid	37	0.44**
Env*Argentine	28	0.42
Env*U.S.	7	0.31
Env.*Argentine*U.S.	2	1.10*
Error	108	0.26
Repeatability		0.54

The overall antilogarithmic aflatoxin mean across environments was 109.42 ng g^{-1}, with a range of 18.57 to 344.83 ng g^{-1} among the hybrids (Table 36). The mean for Argentine hybrids (104.41 ng g^{-1}) was lower than the U.S. hybrid mean (124.44 ng g^{-1}), and probably could have been even lower if two of the Argentine hybrids would not have had aflatoxin levels above 200 ng g^{-1}. All U.S. hybrids had aflatoxin concentrations above 100 ng g^{-1}, but Argentine hybrids AX888IT, AX889, CONDOR, NK900TDMAX, and AGRI124 had aflatoxin below 60 ng g^{-1} (Table 36).

Table 36. Antilogarithmic aflatoxin means (ng g^{-1}) across environments for Argentine and U.S. hybrids.

	Antilogarithmic Aflatoxin[†]
A933	74.95[bcde]
AX877	344.83[a]
AX878	61.53[bcde]
AX882	160.62[abc]
AX884IT	88.39[abcd]
AX888IT	39.23[cde]
AX889	18.57[e]
AX934	241.21[abc]
AX956	144.31[abc]
AX882MG	107.40[abcd]
AX890MG	62.17[bcde]
DK682	96.14[abcd]
CONDOR	25.26[de]
NK900TDMAX	44.28[cde]
AGRI124	57.24[bcde]
DKC66-80	139.06[abc]
DKC69-70	105.95[abcd]
P31B13	165.12[abc]
P32R25	107.62[abcd]
W4700	104.47[abcd]
Overall Mean	109.42
Argentine Mean	104.41
U.S. Check Mean	124.44

[†] Hybrids followed by the same letter are not significantly different from each other at the 0.05 level (LSD).

The singular value decomposition biplot explained 86% of the variation among environments for logarithmic transformation of aflatoxin. The three testing environments for aflatoxin discriminate the hybrids in different manners (Figure 49).

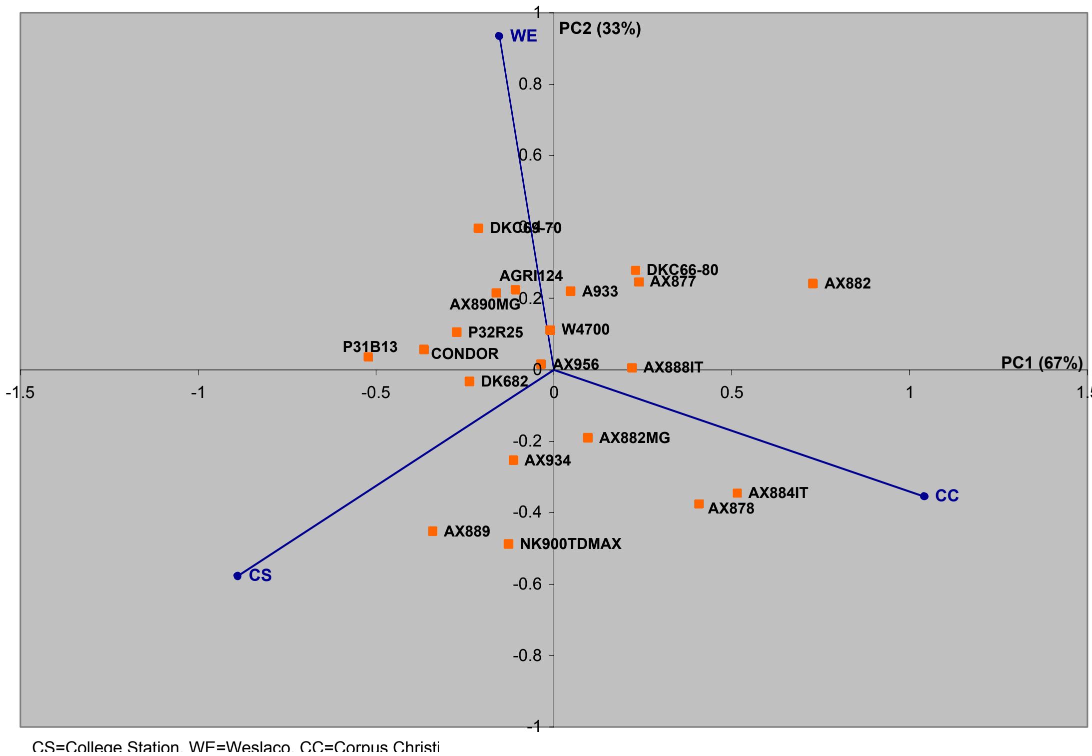


Figure 49. Singular value decomposition biplot of base 10 logarithm of aflatoxin across environments for Argentine and U.S. hybrids.

Relationship Among Traits

The SVD Biplot for hybrids by traits explained 57% across environments (Figure 50). While no traits were positively correlated with aflatoxin, test weight, lodging, and possibly grain moisture were negatively correlated with aflatoxin.

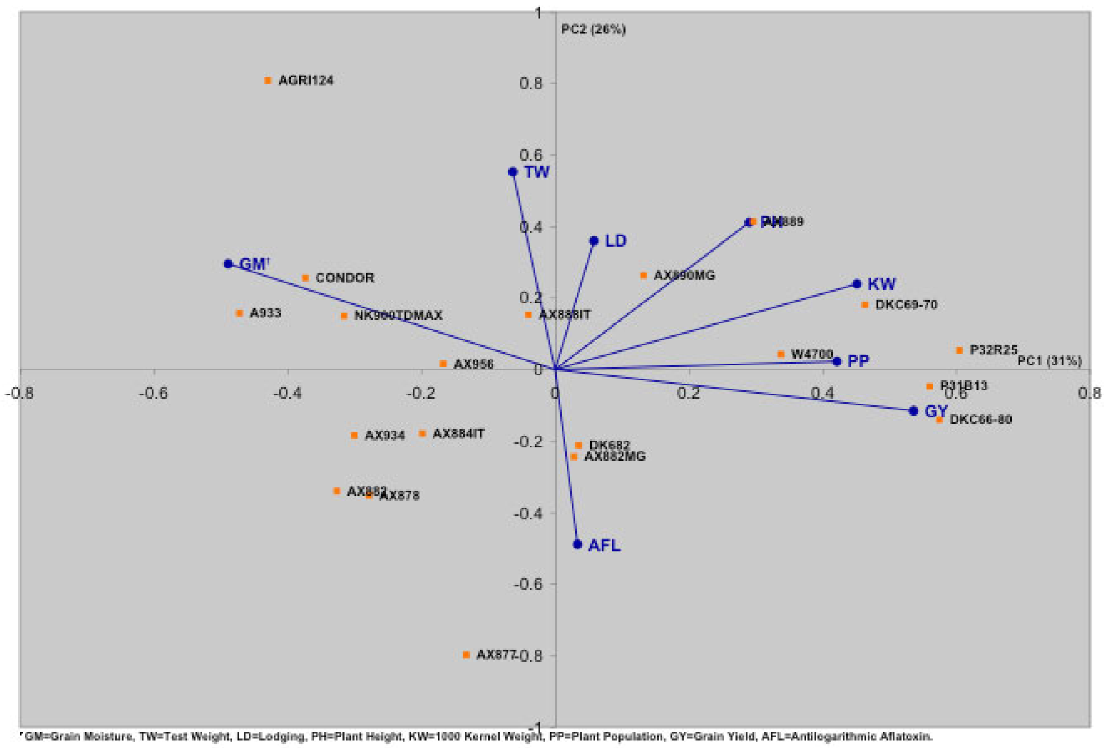


Figure 50. Singular value decomposition biplot of traits across environments for Argentine and U.S. hybrids.

Grain yield means were plotted against aflatoxin means in Figure 51. There was not a clear trend across environments although more aflatoxin was associated with greater yields at Weslaco. Differences can be seen between environments in both how they respond for grain yield and aflatoxin.

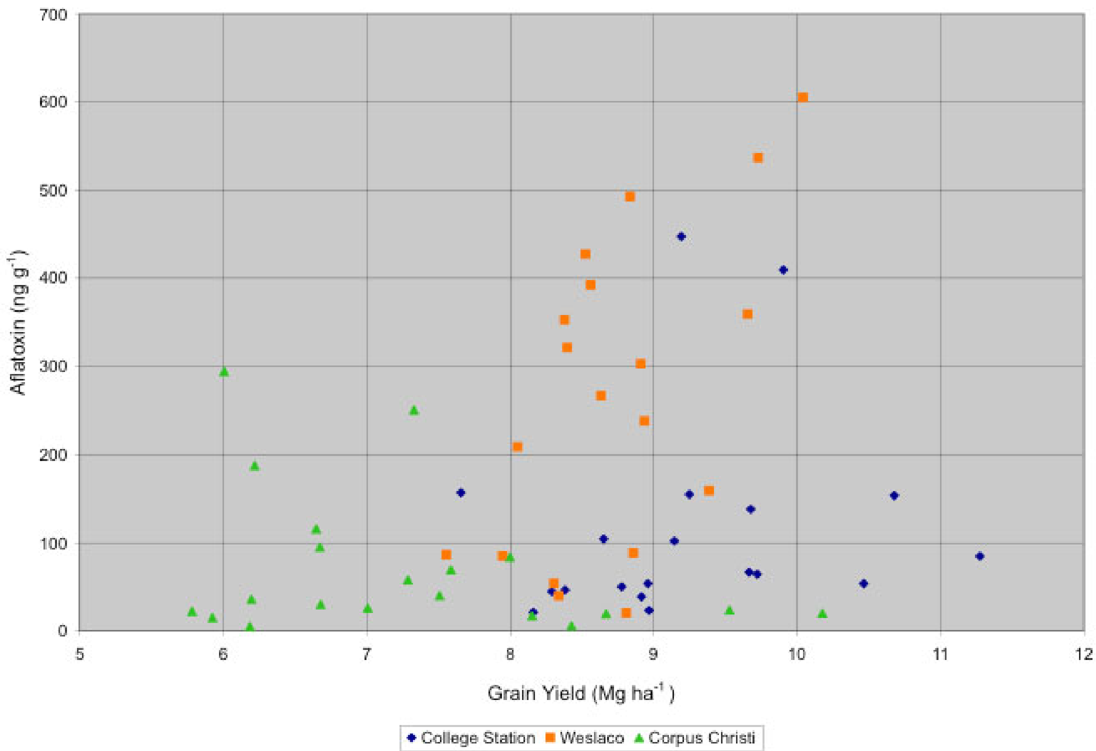


Figure 51. Grain yield (Mg ha^{-1}) vs. antilogarithmic aflatoxin (ng g^{-1}) across environments for Argentine and U.S. hybrids.

One thousand kernel weight means were plotted against aflatoxin means, but again no relationship was evident from this graph (Figure 52). While environmental response to these traits is noticeable, it is not as clear as the grain yield vs. aflatoxin graph.

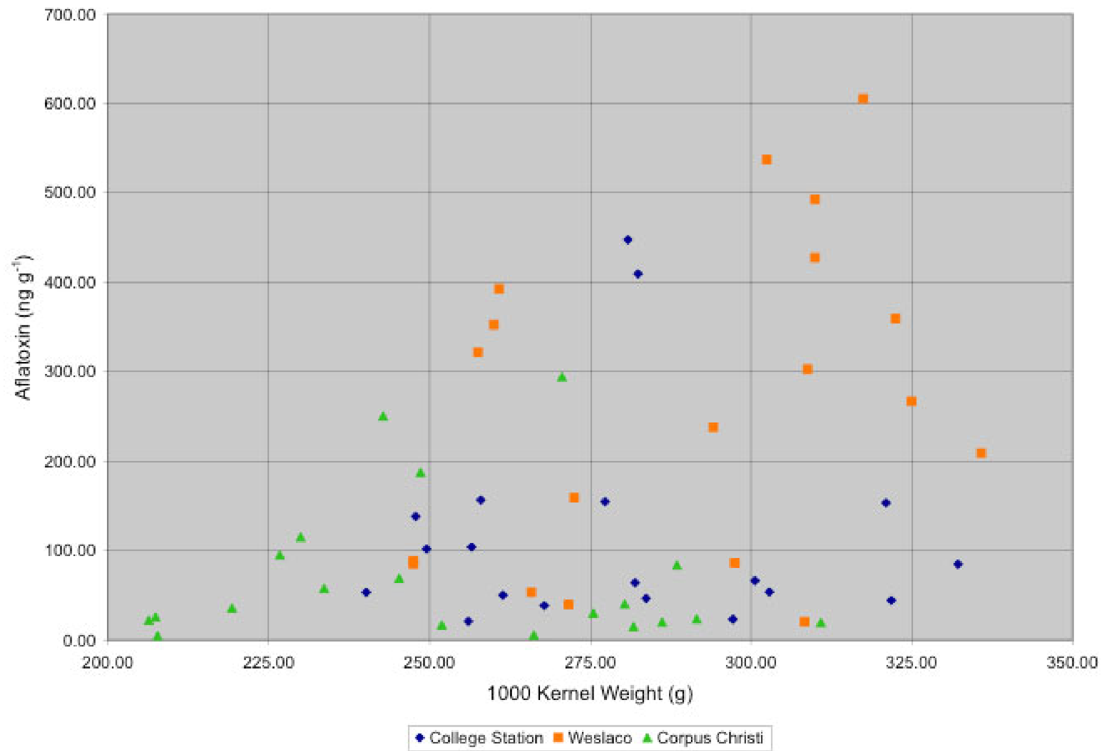


Figure 52. 1000 kernel weight (g) vs. antilogarithmic aflatoxin (ng g^{-1}) across environments for Argentine and U.S. hybrids.

Test weight means were plotted against aflatoxin means, but no relationship between the traits is evident in this graph either (Figure 53). Again this graph can be used to look at environmental response to both 1000 kernel weight and aflatoxin.

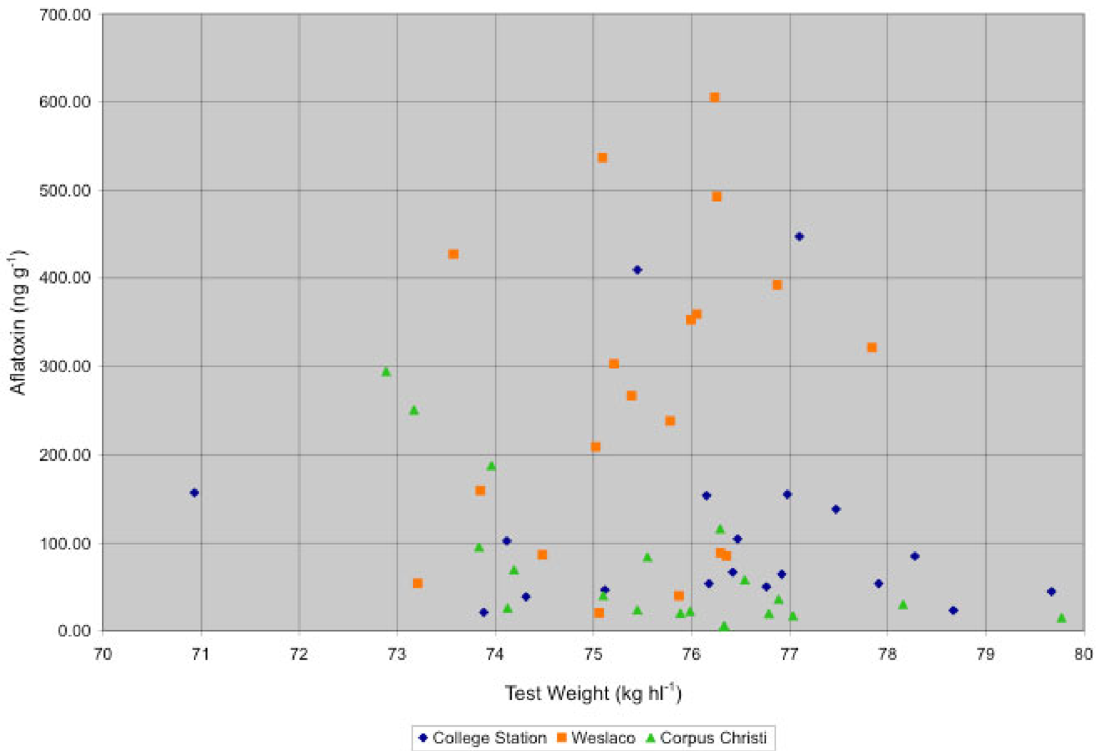


Figure 53. Test weight (kg hl^{-1}) vs. antilogarithmic aflatoxin (ng g^{-1}) across environments for Argentine and U.S. hybrids.

LAMA Testcrosses

Single Environment Analysis

For aflatoxin analysis, only Corpus Christi had significant differences ($P<0.05$) among replications (Table 37). Significant differences ($P<0.05$) among hybrids and between LAMA testcrosses and U.S. hybrids were detected in Weslaco. Repeatabilities were relatively low and ranged from 0.00 to 0.46. Coefficients of variation values were high ranging from 27.98 to 41.15%. Weslaco had the highest repeatability and lowest CV value for aflatoxin (Table 37).

Table 37. Analysis of variance for logarithmic aflatoxin (ng g^{-1}) in different environments for LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square		df	Mean Square
		College Station	Weslaco		Corpus Christi
Reps	2	0.92	0.50	2	4.80**
Hybrids	34	0.45	0.64*	20	0.31
LAMA TC	28	0.39	0.61*	13	0.29
U.S. Hybrids	5	0.77	0.06	6	0.32
LAMA TC*U.S.	1	1.13	3.54**	1	0.47
Error	66	0.66	0.35	40	0.18
Repeatability		0.00	0.46		0.41
C.V., %		41.15	27.98		33.55

Means for aflatoxin concentration were highest in Weslaco, followed by College Station and Corpus Christi respectively (Table 38). In all environments the LAMA testcrosses had lower mean aflatoxin than the U.S. hybrids.

Table 38. Antilogarithmic aflatoxin means (ng g^{-1}) in different environments for LAMA testcrosses and U.S. hybrids.

	----------------------ng g^{-1}----------------------		
	College Station	Weslaco	Corpus Christi[†]
LAMA2002-1-1-B/LH195	38.88	143.45	----
LAMA2002-2-1-B/LH195	223.61	19.05	23.26[abcd]
LAMA2002-5-3-B/LH195	162.37	35.75	63.10[a]
LAMA2002-6-1-B/LH195	358.92	75.28	13.28[abcde]
LAMA2002-8-1-B/LH195	93.43	190.55	----
LAMA2002-9-2-B/LH195	213.65	95.50	29.74[abcd]
LAMA2002-10-1-B/LH195	43.92	37.15	----
LAMA2002-11-1-B/LH195	22.30	85.76	----
LAMA2002-12-1-B/LH195	47.67	5.17	4.40[e]
LAMA2002-13-B2-B/LH195	91.90	234.42	10.72[bcde]
LAMA2002-14-B-B/LH195	82.66	831.76	11.57[bcde]
LAMA2002-16-2-B/LH195	77.64	187.63	----
LAMA2002-17-2-B/LH195	35.20	360.33	6.46[de]
LAMA2002-20-4-B/LH195	77.98	95.50	23.99[abcd]
LAMA2002-22-2-B/LH195	71.43	234.42	8.91[cde]
LAMA2002-23-1-B/LH195	97.32	145.65	----
LAMA2002-25-5-B/LH195	39.57	158.49	19.80[abcde]
LAMA2002-27-1-B/LH195	98.42	99.24	----
LAMA2002-32-4-B/LH195	106.93	31.38	----
LAMA2002-34-1-B/LH195	136.18	81.28	----
LAMA2002-35-5-B/LH195	142.66	328.62	----
LAMA2002-42-B-B/LH195	264.61	50.12	14.02[abcde]
LAMA2002-44-B-B/LH195	114.50	28.40	----
LAMA2002-46-3-B/LH195	31.70	297.37	25.12[abcd]
LAMA2002-55-3-B/LH195	78.89	86.44	----
LAMA2002-56-B-B/LH195	26.75	109.65	----
LAMA2002-58-1-B/LH195	24.18	194.98	38.31[abc]
LAMA2002-60-9-B/LH195	40.19	295.12	----
LAMA2002-61-2-B/LH195	164.10	109.65	----
DKC66-80	98.40	304.30	28.40[abcd]
DKC69-70	85.62	471.30	24.36[abcd]
P31B13	520.83	413.71	60.26[a]
P32R25	91.22	532.97	51.29[ab]
LH195 x LH210	295.12	333.66	10.08[bcde]
DKC69-72	----	----	35.75[abc]
SCR42 x Tx772	----	----	8.51[cde]
Overall Mean	120.55	197.18	24.35
LAMA TC Mean	103.71	160.28	20.90
U.S. Hybrid Mean	218.24	411.19	31.23

[†] Hybrids followed by the same letter are not significantly different from each other at the 0.05 level (LSD).

Across Environment Analysis

Table 39. Analysis of variance for base 10 logarithmic aflatoxin (ng g^{-1}) across environments for LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square
Env	2	14.66**
Rep(Env)	6	2.07**
Hybrid	35	0.58
LAMA TC	28	0.42
U.S. Hybrid	6	0.60
LAMA TC*U.S. Hybrid	1	5.06**
Env*Hybrid	53	0.43
LAMA TC*Env	41	0.49
U.S. Hybrid *Env	10	0.19
LAMA TC*U.S. Hybrid*Env	2	0.37
Error	172	0.43
Repeatability		0.21
C.V., %		35.20

Significant differences ($P<0.05$) were found among environments and replications within environments, but no significant differences ($P<0.05$) were found among hybrids (Table 39). Significant differences ($P<0.05$) were found between U.S. hybrids and LAMA testcrosses. There was not significant ($P<0.05$) environment by hybrid interaction. Repeatability was low (0.21) and the coefficients of variation value was high (35.20%) (Table 39).

There was quite a difference in antilogarithmic aflatoxin means between the U.S. hybrids and LAMA testcrosses, with LAMA testcrosses having much less aflatoxin (57.64 ng g^{-1}) than the U.S. hybrids (127.96 ng g^{-1}) (Table 40). All U.S. hybrids had aflatoxin levels above 100 ng g^{-1} except LH195 x LH210 (82.91 ng g^{-1}) and SCR42 x Tx772 (29.81 ng g^{-1}). None of the LAMA testcrosses had aflatoxin above 100 ng g^{-1} except for TX-LAMA2002-35-5-B/LH195 (146.22 ng g^{-1}). Six LAMA testcrosses had aflatoxin concentrations under 40 ng g^{-1}, and nine had aflatoxin under 50 ng g^{-1} (Table 40).

Table 40. Antilogarithmic aflatoxin hybrid means across environments for LAMA testcrosses and U.S. hybrids.

	Antilogarithmic Aflatoxin
LAMA2002-1-1-B/LH195	30.64
LAMA2002-2-1-B/LH195	54.53
LAMA2002-5-3-B/LH195	56.66
LAMA2002-6-1-B/LH195	74.40
LAMA2002-8-1-B/LH195	78.45
LAMA2002-9-2-B/LH195	82.95
LAMA2002-10-1-B/LH195	23.73
LAMA2002-11-1-B/LH195	24.86
LAMA2002-12-1-B/LH195	9.50
LAMA2002-13-B2-B/LH195	48.35
LAMA2002-14-B-B/LH195	96.72
LAMA2002-16-2-B/LH195	59.68
LAMA2002-17-2-B/LH195	46.03
LAMA2002-20-4-B/LH195	64.94
LAMA2002-22-2-B/LH195	67.66
LAMA2002-23-1-B/LH195	70.27
LAMA2002-25-5-B/LH195	61.99
LAMA2002-27-1-B/LH195	46.63
LAMA2002-32-4-B/LH195	30.87
LAMA2002-34-1-B/LH195	52.69
LAMA2002-35-5-B/LH195	146.22
LAMA2002-42-B-B/LH195	57.33
LAMA2002-44-B-B/LH195	26.94
LAMA2002-46-3-B/LH195	63.74
LAMA2002-55-3-B/LH195	39.45
LAMA2002-56-B-B/LH195	59.99
LAMA2002-58-1-B/LH195	63.10
LAMA2002-60-9-B/LH195	50.97
LAMA2002-61-2-B/LH195	82.28
DKC66-80	97.43
DKC69-70	112.62
P31B13	295.94
P32R25	139.12
LH195 x LH210	82.91
DKC69-72	137.91
SCR42 x Tx772	29.81
Overall Mean	71.31
LAMA TC Mean	57.64
U.S. Hybrid Mean	127.96

Discussion and Conclusions

Argentine Hybrids

Environmental means for aflatoxin concentrations ranged from 70.80 ng g^{-1} in Corpus to 322.63 ng g^{-1} in Weslaco in the Argentine hybrid experiment. In all three environments the Argentine hybrids had some of the lowest aflatoxin means, as well as overall. Hybrid AX888IT had the lowest aflatoxin mean in College Station, AX889 had the lowest mean in Weslaco, and CONDOR had the lowest mean in Corpus Christi. AX889 had the lowest aflatoxin mean across environments. In each environment many of the Argentine hybrids had aflatoxin means less than 50 ng g^{-1}, but among the U.S. hybrids only DKC69-70, P31B13, P32R25, and W4700 in Corpus Christi had aflatoxin under 50 ng g^{-1}. Over all environments, all U.S. hybrids had aflatoxin means above 100 ng g^{-1}, but ten Argentine hybrids had aflatoxin means lower than 100 ng g^{-1}, and four hybrids, AX888IT, AX889, CONDOR, and NK900TDMAX had aflatoxin means under 50 ng g^{-1}.

The three different testing environments for aflatoxin discriminated the hybrids in different manners in the Argentine hybrid experiment. No positive correlations among aflatoxin and other traits were seen for this experiment, although test weight, lodging, and possibly grain moisture were negatively correlated with aflatoxin.

Many of the Argentine hybrids had such low aflatoxin levels, they could be used in breeding programs in the southern U.S., where aflatoxin poses major problems for producers, to help reduce aflatoxin contamination in U.S. temperate maize. If aflatoxin resistance could be coupled with high grain yields in an agronomically elite hybrid, the hybrids would be very competitive with U.S. hybrids in hot and dry environments found in the southern U.S.

More research is needed to determine the cause of the resistance in the Argentine hybrids and whether or not it is heritable. Multiple years and environments are also needed for testing to make sure that the hybrids that show reduced levels of aflatoxin in these studies are truly resistant. However, judging by the differences in these materials, husk cover, kernel structure, and resistance to abiotic stresses might play a big role in Argentine hybrids having reduced aflatoxin concentrations.

LAMA Testcrosses

Single environments for the LAMA testcrosses were not able to discriminate easily among hybrids as only Corpus Christi showed significant differences ($P<0.05$). Overall the LAMA testcrosses had lower aflatoxin means than the U.S. hybrids. In single environments ten LAMA testcrosses had aflatoxin means under 50 ng g^{-1} in College Station, six LAMA testcrosses had aflatoxin means under 50 ng g^{-1} in Weslaco, and thirteen out of fourteen LAMA testcrosses had aflatoxin means under 50 ng g^{-1} in Corpus Christi. Only in Corpus Christi did any U.S. hybrids have less than 50 ng g^{-1} for hybrid means, with four out of six U.S. hybrids in that environment showing less than 50 ng g^{-1}.

Across environments, four LAMA testcrosses, TX-LAMA2002-10-1-B/LH195, TX-LAMA2002-11-1-B/LH195, TX-LAMA2002-12-1-B/LH195, and TX-LAMA2002-44-B-B/LH195 had aflatoxin means under 30 ng g^{-1}. Only one U.S. check, SCR42 x Tx772 had an aflatoxin mean lower than 30 ng g^{-1}. Ten of the LAMA testcrosses had aflatoxin means below 50 ng g^{-1}, and all but one, TX-LAMA2002-35-5-B/LH195, had aflatoxin means under 100 ng g^{-1}, whereas all but three U.S. hybrids had aflatoxin means over 100 ng g^{-1} across environments.

With such low aflatoxin levels under inoculation these LAMA testcrosses show great promise for use in breeding programs to reduce aflatoxin contamination. Again these exotic lines should be testcrossed with other elite inbreds to evaluate their true value. The source of their resistance needs to be determined through further testing under different environments and inoculation methods. There are different type of combinations among exotic and temperate lines that can result in elite, high yielding hybrids that are resistant to aflatoxin. As some resistance to aflatoxin was observed in testcrosses with 50% exotic and 50% temperate (LH195), we expect that those possible aflatoxin resistance factors in LAMA lines can be passed on to offspring and contribute to reduce aflatoxin contamination in Southern U.S.

CHAPTER VI

SUMMARY

Argentine Hybrids

Several of the Argentine hybrids had grain yields that were competitive with the U.S. hybrids. Argentine hybrids AX889 and AX882MG had overall grain yield means above that of U.S. hybrid W4700 (Table 17). In individual environments several of the Argentine hybrids performed well for grain yield.

AX878 was the highest yielding hybrid in Wharton and Prosper, and was quite competitive in the other environments except for the two southernmost environments (Weslaco and Corpus Christi) and the northernmost (Dalhart) environment (Table 5). AX890MG was the highest yielding hybrid in Bardwell, and was one of the higher yielders in Granger and Halfway, AX882MG was similarly a top yielding hybrid in several environments. Most of the Argentine hybrids performed well in several environments but not as well in others, whereas the U.S. hybrids performed well in most all environments for grain yield.

For test weight AGRI124 had the highest overall mean followed by A933, AX88IT, CONDOR, and DK682 (Table 17). The highest 1000 kernel weights were found for DKC69-70, P32R25, and AGRI124. High lodging percentages (meaning potential problem for standability) for hybrids AX889, AX890MG, and AGRI124 might limit the utilization of these hybrids in production agriculture in the U.S. Lodging did not appear correlated with plant height however, as the tallest hybrids were U.S. hybrids but the same hybrids had less incidence of lodging. High grain moisture could be a problem for AGRI124, AX934, NK900TDMAX, and A933 as they had grain moistures over 17% at harvest and would require more time in the field (exposure to weather and aflatoxin) or mechanical drying (fuel expenses) during storage (Table 17).

Overall several of these hybrids were competitive with commercial U.S. hybrids, and although they might not out yield current elite hybrids, they also haven't undergone selection for the same traits and adaptation area. Argentine hybrids AX889, AX882MG, and AX890MG had competitive grain yields and were stable across environments. These and other exotic hybrids could provide useful and novel alleles for different traits and productivity if they were incorporated into a breeding program and should also broaden genetic variation in the U.S. temperate maize germplasm. They could also contribute to grain quality as they could be used to raise test weights and kernel hardness attributes. While they probably aren't directly that useful to producers as commercial hybrids, creation of inbred lines or populations with this material should be useful in maize improvement.

LAMA Testcrosses

In the LAMA testcrosses, TX-LAMA2002-9-2-B/LH195 had higher overall grain yield mean than two of the U.S. hybrids, and was comparable to the others (Table 31). Both TX-LAMA2002-13-B2-B/LH195 and TX-LAMA2002-44-B-B/LH195 were poor performers for grain yield with overall yield less than 8.00 Mg ha^{-1}. In individual environments several of the LAMA testcrosses performed as well or similarly to U.S. hybrids, and in Dumas TX-LAMA2002-6-1-B/LH195, TX-LAMA2002-9-2-B/LH195, and TX-LAMA2002-17-2-B/LH195 performed very well in relation to the U.S. hybrids (Table 21). In Weslaco and Corpus Christi the LAMA testcrosses did not perform as well for grain yield as they did in the environments farther north. It would be interesting to evaluate these testcrosses in the Corn Belt to see if they continue to show adaptation in northern environments.

LAMA testcrosses had heavier test weights than the U.S. hybrids. Testcrosses TX-LAMA2002-44-B-B/LH195 and TX-LAMA2002-46-3-B/LH195 had test weights over 78.00 kg hl^{-1} (Table 31). Several others including TX-LAMA2002-9-2-B/LH195 had test weights above 77.50 kg hl^{-1}. In College Station and Castroville, the highest test weight means were recorded with TX-LAMA2002-44-B-B/LH195 and TX-LAMA2002-14-B-B/LH195 having test weights above 80.00 kg hl^{-1} in College Station. Hybrid TX-LAMA2002-44-B-B/LH195 had test weights above 80.00 kg hl^{-1} in Castroville (Table 23).

Surprisingly, lodging percentage did not seem to be an issue for any of the testcrosses except for TX-LAMA2002-5-3-B/LH195, which had lodging mean of 14.59% (Table 31). LAMA testcrosses TX-LAMA2002-20-4-B/LH195, TX-LAMA2002-14-B-B/LH195, and TX-LAMA2002-6-1-B/LH195 had lower lodging means than all but two of the U.S. hybrids. Lodging was reduced in this experiment possibly due to selection pressure for standability during line development. In addition the LAMA testcrosses had a shorter overall plant height mean than the U.S. hybrids.

Increased grain moisture does not appear to be a problem for the LAMA testcrosses, as most are competitive with U.S. hybrids, and even the highest LAMA testcross grain moisture means are still less than 16% moisture (Table 31).

Aflatoxin Evaluation

Both Argentine hybrids and LAMA testcrosses show promise in providing novel alleles to reduce aflatoxin contamination. In both groups, several hybrids had aflatoxin levels less than 50 ng g^{-1}. While aflatoxin resistance is a difficult trait to incorporate and evaluate, the Argentine hybrids and LAMA testcrosses consistently had less aflatoxin contamination than the U.S. hybrids both in different environments and across environments.

Among environments, Weslaco had the highest aflatoxin means and Corpus Christi had the lowest means. Results were somewhat variable across environments, but field variation didn’t seem to present major issues.

Among Argentine hybrids, AX889, CONDOR, AX888IT, and NK900TDMAX had the lowest means for aflatoxin concentration. Several other Argentine hybrids had aflatoxin levels lower than 100 ng g^{-1} (Table 36). The U.S. hybrids all had aflatoxin concentrations above 100 ng g^{-1}. Reduced aflatoxin contamination coupled with competitive yields could make AX889 an attractive hybrid for Texas farmers, and excellent candidate to use their parental inbreds in breeding to improve hybrid performance in Texas.

For the LAMA testcross experiment, all but one hybrid TX-LAMA2002-35-5-B/LH95, had aflatoxin concentrations below 100 ng g^{-1} (Table 40). Several, including

TX-LAMA2002-1-1-B/LH195, TX-LAMA2002-10-1-B/LH195, TX-LAMA2002-11-1-B/LH195, TX-LAMA2002-12-1-B/LH195, TX-LAMA2002-32-4-B/LH195, TX-LAMA2002-44-B-B/LH195 had aflatoxin below 30 ng g^{-1}. The only U.S. hybrid that had aflatoxin below 30 was SCR42 x Tx772. The results from this aflatoxin evaluation seem very promising for these materials that could be used for breeding materials to reduce aflatoxin contamination.

While these materials need to be evaluated with other testers, and in more environments, the preliminary results are promising. This exotic maize would also benefit from additional cycles of selection for adaptation and productivity. These experiments showed that elite exotic maize germplasm from South America have potential for broadening the genetic diversity of temperate U.S. maize and possibly adding alleles for productivity, grain traits, and aflatoxin resistance.

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APPENDIX

Table 41. Analysis of variance for plant population (plants ha^{-1}) in Texas environments for complete set of LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS†	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square WE	df	Mean Square CC
Reps	1	0.63	1	9.58	1	0.52	1	5.05	1	56.55	2	41.33	2	20.11
Hybrids	28	58.72*	29	27.37**	22	22.56*	20	8.05	17	50.68	33	15.79	20	55.28
Error	28	28.17	31	9.03	22	8.27	20	11.05	17	38.38	66	14.27	40	37.75
Repeatability		0.52		0.67		0.63		0.00		0.24		0.10		0.32
C.V.		6.40		4.65		4.67		6.00		10.06		6.68		6.77

† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco, CC=Corpus Christi.

Table 42. Analysis of variance for grain yield (Mg ha^{-1}) in Texas environments for complete set of LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS†	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square WE	df	Mean Square CC
Reps	1	0.00	1	0.16	1	1.24	1	0.00	1	2.23	2	6.03**	2	0.65
Hybrids	28	1.00**	29	2.82**	22	0.69	20	0.87	17	4.21**	33	1.76*	20	3.68**
Error	28	0.40	31	0.51	22	0.41	20	0.47	17	0.84	66	0.90	40	0.66
Repeatability		0.60		0.82		0.40		0.46		0.80		0.49		0.82
C.V.		6.30		8.71		9.02		7.84		9.38		13.13		10.10

† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco, CC=Corpus Christi.

Table 43. Analysis of variance for test weight (kg hl^{-1}) in Texas environments for complete set of LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS†	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square WE
Reps	1	0.25	1	0.00	1	0.18	1	0.66	1	0.47	2	0.44
Hybrids	28	4.41**	29	4.00**	22	6.74*	20	3.68**	17	1.54	33	5.73**
Error	28	0.23	31	0.95	22	2.93	20	0.53	17	0.76	63	0.56
Repeatability		0.95		0.76		0.57		0.86		0.51		0.90
C.V.		0.61		1.25		2.25		0.94		1.17		0.98

† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.

Table 44. Analysis of variance for grain moisture (%) in Texas environments for complete set of LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS†	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square WE
Reps	1	0.00	1	0.19	1	0.13	1	0.14	1	2.45	2	9.08**
Hybrids	28	1.22**	29	3.96**	22	5.61**	20	0.84**	17	5.40**	33	4.26**
Error	28	0.11	31	0.10	22	0.23	20	0.07	17	0.90	66	0.97
Repeatability		0.91		0.98		0.96		0.92		0.83		0.77
C.V.		2.76		2.41		3.42		2.15		4.81		6.25

† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.

Table 45. Analysis of variance for plant height (cm) in Texas environments for complete set of LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS†	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square CS
Reps	1	28.48	1	26.64	1	213.32	1	258.22	1	172.22	1	566.29**
Hybrids	28	142.92	29	260.86**	22	202.89	20	230.84**	17	151.98*	33	384.84**
Error	28	93.91	31	75.52	22	114.79	20	61.44	17	66.72	66	113.18
Repeatability		0.34		0.71		0.43		0.73		0.56		0.71
C.V.		3.81		3.69		4.27		3.56		2.74		4.26

† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, CS=College Station.

Table 46. Analysis of variance for lodging (%) in Texas environments for complete set of LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square CS†	df	Mean Square CA	df	Mean Square WH	df	Mean Square BA	df	Mean Square DU	df	Mean Square WE
Reps	1	0.00	1	0.16	1	1.25	1	0.00	1	13.20	2	41.82
Hybrids	28	1.00**	29	2.67**	22	0.69	20	0.87	17	31.31*	33	87.35**
Error	28	0.39	31	0.46	22	0.41	20	0.47	17	11.92	66	40.11
Repeatability		0.61		0.83		0.41		0.46		0.62		0.54
C.V., %		6.25		8.18		9.01		7.84		73.91		124.04

† CS=College Station, CA=Castroville, WH=Wharton, BA=Bardwell, DU=Dumas, WE=Weslaco.

Table 47. Analysis of variance across environments for plant population, grain yield, test weight, plant height, lodging percentage, and grain moisture for complete set of LAMA testcrosses and U.S. hybrids.

Source	df	Mean Square	df	Mean Square	df	Mean Square	df	Mean Square	df	Mean Square	df	Mean Square
		--pl ha^{-1}--		--Mg ha^{-1}--		--kg hl^{-1}--		--cm--		--%--		--%--
Env	6	10470.62**	6	58.43**	5	64.35**	6	20638.58**	5	181.27**	5	325.54**
Rep(Env)	9	744.05	9	1.89**	7	0.35	7	261.64**	7	14.04	7	3.01**
Hybrid	53	535.72	53	3.22**	50	8.43**	50	357.94**	50	45.55**	50	5.99**
Hybrid*Env	116	1003.36**	116	1.58**	99	2.57**	132	122.34	99	11.20	99	2.28**
Error	224	599.80	224	0.65	181	0.88	184	94.18	184	15.73	184	0.50
C.V., %		35.50		9.75		1.22		3.91		55.37		4.92

Table 48. Plant height, grain yield, grain moisture, and test weight means in College Station for complete set of LAMA testcrosses and U.S. hybrids.

	College Station			
	--cm--	--Mg ha^{-1}--	--%--	--kg hl^{-1}--
LAMA2002-1-1-B/LH195	254.00	9.39	11.69	77.56
LAMA2002-2-1-B/LH195	243.84	9.13	12.15	79.18
LAMA2002-5-3-B/LH195	260.35	9.85	11.69	77.69
LAMA2002-6-1-B/LH195	259.08	10.38	10.89	76.19
LAMA2002-9-2-B/LH195	261.62	10.19	10.81	79.12
LAMA2002-10-1-B/LH195	248.92	10.23	12.95	79.62
LAMA2002-11-1-B/LH195	247.65	9.48	13.41	80.44
LAMA2002-12-1-B/LH195	265.43	9.41	12.48	79.48
LAMA2002-13-B2-B/LH195	236.22	9.61	11.76	78.61
LAMA2002-14-B-B/LH195	242.57	9.94	12.19	80.27
LAMA2002-17-2-B/LH195	262.89	9.68	11.46	78.35
LAMA2002-20-4-B/LH195	247.65	10.15	12.65	79.72
LAMA2002-22-2-B/LH195	257.81	10.19	12.49	79.51
LAMA2002-23-1-B/LH195	240.03	8.90	12.28	78.54
LAMA2002-25-5-B/LH195	254.00	10.12	11.67	77.49
LAMA2002-32-4-B/LH195	254.00	10.35	12.30	80.71
LAMA2002-34-1-B/LH195	261.62	9.99	12.42	78.47
LAMA2002-35-5-B/LH195	250.19	8.93	11.87	78.45
LAMA2002-42-B-B/LH195	265.43	9.69	11.85	79.36
LAMA2002-44-B-B/LH195	259.08	9.11	11.94	80.13
LAMA2002-46-3-B/LH195	270.51	9.47	12.58	79.55
LAMA2002-58-1-B/LH195	255.27	10.98	11.66	78.44
LAMA2002-61-2-B/LH195	245.11	9.63	12.53	80.62
DKC66-80	248.92	10.95	10.42	75.83
DKC69-70	250.19	11.27	12.05	77.65
P31B13	266.70	11.35	10.67	77.40
P32R25	256.54	10.05	10.40	75.50
LH195 x LH210	257.81	10.59	10.50	75.65
DKC69-72	255.27	11.49	11.11	77.26
LSD (0.05)†	19.85	1.29**	0.66**	0.98**
Overall Mean	254.44	10.01	11.82	78.51
LAMA TC Mean	254.06	9.77	12.07	79.02
U.S. Hybrid Mean	255.91	10.95	10.86	76.55

† Fisher's least significant difference, use to compare individual hybrids.

Table 49. Plant height, grain yield, grain moisture, and test weight means in Castroville for complete set of LAMA testcrosses and U.S. hybrids.

	Castroville			
	--cm--	--Mg ha^{-1}--	--%--	--kg hl^{-1}--
LAMA2002-1-1-B/LH195	217.17	5.76	12.45	77.75
LAMA2002-2-1-B/LH195	218.44	6.31	12.90	77.61
LAMA2002-5-3-B/LH195	232.41	8.91	13.40	77.72
LAMA2002-6-1-B/LH195	243.84	7.85	12.25	76.63
LAMA2002-9-2-B/LH195	252.73	9.48	12.20	79.43
LAMA2002-10-1-B/LH195	250.19	8.63	16.20	77.45
LAMA2002-11-1-B/LH195	224.79	7.68	15.30	77.85
LAMA2002-12-1-B/LH195	254.00	8.54	14.80	77.88
LAMA2002-13-B2-B/LH195	223.52	6.72	13.45	79.95
LAMA2002-14-B-B/LH195	222.25	7.01	13.95	78.58
LAMA2002-17-2-B/LH195	236.22	8.15	12.20	77.74
LAMA2002-20-4-B/LH195	229.87	8.11	14.70	79.88
LAMA2002-22-2-B/LH195	238.76	8.52	14.40	79.28
LAMA2002-23-1-B/LH195	217.17	7.52	13.50	77.12
LAMA2002-25-5-B/LH195	229.87	7.32	12.15	76.67
LAMA2002-32-4-B/LH195	241.30	9.36	13.95	77.80
LAMA2002-34-1-B/LH195	240.03	9.93	14.25	76.17
LAMA2002-42-B-B/LH195	247.65	9.60	13.05	80.27
LAMA2002-44-B-B/LH195	252.73	8.69	14.15	80.03
LAMA2002-46-3-B/LH195	245.11	8.30	13.25	79.64
LAMA2002-58-1-B/LH195	232.41	8.48	12.95	76.90
LAMA2002-61-2-B/LH195	237.49	9.11	13.45	80.09
DKC66-80	236.22	8.94	11.23	75.84
DKC69-70	234.95	7.97	12.65	78.21
P31B13	233.68	8.07	11.30	77.03
P32R25	245.11	7.93	10.95	75.85
LH195 x LH210	238.76	8.20	11.30	75.92
DKC69-72	243.84	9.58	11.90	77.34
SCR42 x Tx772	212.09	4.33	11.15	75.47
RX897	228.60	9.77	10.90	74.88
LSD (0.05)†	17.62**	1.30**	0.63**	1.62**
Overall Mean	235.37	8.16	13.01	77.77
LAMA TC Mean	235.82	8.18	13.59	78.29
U.S. Hybrid Mean	234.16	8.10	11.42	76.32

† Fisher's least significant difference, use to compare individual hybrids.

Table 50. Plant height, grain yield, grain moisture, and test weight means in Wharton for complete set of LAMA testcrosses and U.S. hybrids.

	Wharton			
	--cm--	--Mg ha^{-1}--	--%--	--kg hl^{-1}--
LAMA2002-1-1-B/LH195	245.11	7.26	14.40	75.78
LAMA2002-2-1-B/LH195	236.22	7.25	14.75	76.93
LAMA2002-5-3-B/LH195	246.38	7.46	13.90	75.79
LAMA2002-6-1-B/LH195	259.08	7.48	13.05	75.58
LAMA2002-9-2-B/LH195	260.35	7.82	13.15	77.90
LAMA2002-12-1-B/LH195	270.51	6.86	16.30	74.66
LAMA2002-13-B2-B/LH195	240.03	6.55	14.65	76.54
LAMA2002-14-B-B/LH195	229.87	6.74	16.30	76.02
LAMA2002-17-2-B/LH195	254.00	6.42	14.30	75.41
LAMA2002-20-4-B/LH195	241.30	7.23	16.25	76.92
LAMA2002-22-2-B/LH195	247.65	6.62	15.60	74.94
LAMA2002-25-5-B/LH195	246.38	8.00	12.20	76.43
LAMA2002-32-4-B/LH195	265.43	7.37	14.20	79.01
LAMA2002-34-1-B/LH195	246.38	6.47	13.20	78.51
LAMA2002-42-B-B/LH195	243.84	7.32	14.95	77.01
LAMA2002-44-B-B/LH195	241.30	5.93	14.95	78.36
LAMA2002-46-3-B/LH195	251.46	7.53	16.60	78.94
LAMA2002-58-1-B/LH195	256.54	6.49	14.40	78.94
DKC66-80	252.73	7.72	11.40	73.28
DKC69-70	254.00	7.72	12.85	72.40
P31B13	255.27	7.72	11.15	74.77
P32R25	264.16	7.68	11.10	73.24
LH195 x LH210	261.62	6.37	12.15	76.24
LSD (0.05)†	22.21	1.27	0.99**	3.19*
Overall Mean	250.85	7.13	13.99	76.24
LAMA TC Mean	248.99	7.04	14.62	76.87
U.S. Hybrid Mean	257.56	7.44	11.73	73.99

† Fisher's least significant difference, use to compare individual hybrids.

Table 51. Plant height, grain yield, grain moisture, and test weight means in Bardwell for complete set of LAMA testcrosses and U.S. hybrids.

	Bardwell			
	--cm--	--Mg ha^{-1}--	--%--	--kg hl^{-1}--
LAMA2002-2-1-B/LH195	209.55	8.60	12.65	78.14
LAMA2002-5-3-B/LH195	220.98	8.91	11.80	76.17
LAMA2002-6-1-B/LH195	222.25	8.63	11.70	75.99
LAMA2002-9-2-B/LH195	233.68	9.32	11.65	77.34
LAMA2002-12-1-B/LH195	234.95	9.12	12.50	77.47
LAMA2002-13-B2-B/LH195	205.74	7.80	12.65	77.15
LAMA2002-14-B-B/LH195	196.85	9.38	12.90	77.87
LAMA2002-17-2-B/LH195	214.63	7.93	12.30	77.08
LAMA2002-20-4-B/LH195	205.74	7.99	13.05	78.08
LAMA2002-22-2-B/LH195	229.87	8.79	13.10	77.97
LAMA2002-25-5-B/LH195	210.82	8.28	11.75	75.34
LAMA2002-42-B-B/LH195	214.63	8.65	12.65	78.54
LAMA2002-46-3-B/LH195	228.60	8.98	13.30	78.36
LAMA2002-58-1-B/LH195	223.52	8.65	12.55	78.09
DKC66-80	222.25	9.05	11.55	75.53
DKC69-70	228.60	9.77	12.55	77.31
P31B13	232.41	8.26	11.55	75.29
P32R25	231.14	8.47	11.00	74.73
W4700	220.98	9.82	11.40	75.23
DKC69-72	228.60	9.71	12.00	76.24
SCR42 x Tx772	210.82	7.51	12.80	79.89
LSD (0.05)†	16.35**	1.42	0.55**	1.52**
Overall Mean	220.31	8.74	12.26	77.04
LAMA TC Mean	217.99	8.64	12.47	77.40
U.S. Hybrid Mean	224.97	8.94	11.84	76.31

† Fisher's least significant difference, use to compare individual hybrids.

Table 52. Plant height, grain yield, grain moisture, test weight, and lodging means in Dumas for complete set of LAMA testcrosses and U.S. hybrids.

	Dumas				
	--cm--	--Mg ha^{-1}--	--%--	--kg hl^{-1}--	--%--
LAMA2002-6-1-B/LH195	308.61	11.34	20.59	72.72	4.74
LAMA2002-9-2-B/LH195	308.61	11.61	22.15	75.94	3.89
LAMA2002-13-B2-B/LH195	292.10	6.94	18.67	73.88	4.53
LAMA2002-14-B-B/LH195	294.64	9.89	22.23	75.42	5.53
LAMA2002-17-2-B/LH195	311.15	10.76	21.19	75.42	0.00
LAMA2002-20-4-B/LH195	281.94	8.32	20.21	74.39	5.33
LAMA2002-22-2-B/LH195	303.53	8.89	19.26	74.90	3.03
LAMA2002-19-B-B/LH195	304.80	9.23	19.17	74.13	3.72
LAMA2002-42-B-B/LH195	294.64	7.20	18.51	75.68	3.44
LAMA2002-46-3-B/LH195	297.18	9.62	16.70	74.65	5.77
LAMA2002-7-2-B/LH195	288.29	11.59	17.63	75.42	1.60
DKC66-80	288.29	11.17	19.78	74.13	1.55
DKC69-70	300.99	10.77	19.10	75.42	5.85
P31B13	294.64	10.24	18.10	73.87	2.95
P32R25	295.91	10.47	19.30	74.39	5.95
W4700	289.56	9.68	24.25	74.39	18.52
DKC69-72	311.15	9.31	19.54	73.75	5.63
SCR42 x Tx772	304.80	8.77	19.34	73.36	3.76
LSD (0.05)†	17.23*	1.78**	1.77**	1.84	5.65*
Overall Mean	298.38	9.77	19.76	74.55	4.76
LAMA TC Mean	298.68	9.58	19.66	74.78	3.78
U.S. Hybrid Mean	297.91	10.06	19.92	74.19	6.31

† Fisher's least significant difference, use to compare individual hybrids.

Table 53. Grain yield, grain moisture, test weight, lodging, and logarithmic aflatoxin means in Weslaco for complete set of LAMA testcrosses and U.S. hybrids.

	Weslaco				
	--Mg ha^{-1}--	--%--	--kg hl^{-1}--	--%--	--Log(ng g^{-1})--
LAMA2002-1-1-B/LH195	7.35	15.88	74.85	1.52	2.16
LAMA2002-2-1-B/LH195	7.69	15.67	76.96	3.53	1.28
LAMA2002-5-3-B/LH195	6.54	15.11	75.04	24.19	1.55
LAMA2002-6-1-B/LH195	7.48	14.01	73.99	0.00	1.88
LAMA2002-8-1-B/LH195	6.80	15.91	78.29	6.31	2.28
LAMA2002-9-2-B/LH195	6.92	14.14	77.57	5.34	1.98
LAMA2002-10-1-B/LH195	5.96	17.63	76.54	8.06	1.57
LAMA2002-11-1-B/LH195	7.54	18.51	76.77	0.71	1.93
LAMA2002-12-1-B/LH195	8.30	17.83	77.06	3.03	0.71
LAMA2002-13-B2-B/LH195	7.02	14.66	76.01	3.90	2.37
LAMA2002-14-B-B/LH195	6.63	16.58	77.72	2.90	2.92
LAMA2002-16-2-B/LH195	6.67	17.15	76.35	3.13	2.27
LAMA2002-17-2-B/LH195	7.99	16.14	76.98	0.72	2.56
LAMA2002-20-4-B/LH195	7.56	15.70	76.02	2.97	1.98
LAMA2002-22-2-B/LH195	6.99	15.69	75.01	7.61	2.37
LAMA2002-23-1-B/LH195	5.97	17.45	75.95	2.38	2.16
LAMA2002-25-5-B/LH195	6.78	15.80	74.81	2.50	2.20
LAMA2002-27-1-B/LH195	6.14	15.13	74.08	4.56	2.00
LAMA2002-32-4-B/LH195	7.80	16.14	80.08	15.37	1.50
LAMA2002-34-1-B/LH195	7.64	15.24	76.43	6.14	1.91
LAMA2002-35-5-B/LH195	5.79	15.49	75.98	10.04	2.52
LAMA2002-42-B-B/LH195	6.89	14.55	76.05	6.51	1.70
LAMA2002-44-B-B/LH195	7.48	17.54	78.92	10.01	1.45
LAMA2002-46-3-B/LH195	7.54	16.26	77.16	18.30	2.47
LAMA2002-55-3-B/LH195	7.87	15.64	77.72	3.55	1.94
LAMA2002-56-B-B/LH195	8.15	14.82	77.17	4.89	2.04
LAMA2002-58-1-B/LH195	6.84	16.22	77.99	5.12	2.29
LAMA2002-60-9-B/LH195	6.83	15.84	75.71	5.68	2.47
LAMA2002-61-2-B/LH195	7.35	16.44	78.12	0.00	2.04
DKC66-80	8.25	13.38	74.87	1.45	2.48
DK697	9.34	16.10	77.35	0.74	2.67
P31B13	7.87	14.06	75.61	0.00	2.62
P32R25	7.57	14.40	75.64	0.76	2.73
LH195 x LH210	7.38	14.58	75.04	0.71	2.52
LSD (0.05)†	1.61*	1.61**	1.25**	10.52**	0.98*
Overall Mean	7.26	15.76	76.47	5.08	2.10
LAMA TC Mean	7.12	15.97	76.60	5.83	2.02
U.S. Hybrid Mean	8.08	14.50	75.70	0.73	2.60

† Fisher's least significant difference, use to compare individual hybrids.

Table 54. Grain yield and antilogarithmic aflatoxin means in Corpus Christi for complete set of LAMA testcrosses and U.S. hybrids.

	Corpus Christi	
	-----Mg ha^{-1}-----	-----Log(ng g^{-1})-----
LAMA2002-2-1-B/LH195	8.33	1.37
LAMA2002-5-3-B/LH195	7.64	1.80
LAMA2002-6-1-B/LH195	8.12	1.12
LAMA2002-9-2-B/LH195	7.97	1.47
LAMA2002-12-1-B/LH195	7.14	0.64
LAMA2002-13-B2-B/LH195	7.04	1.03
LAMA2002-14-B-B/LH195	7.74	1.06
LAMA2002-17-2-B/LH195	8.16	0.81
LAMA2002-20-4-B/LH195	7.69	1.38
LAMA2002-22-2-B/LH195	7.81	0.95
LAMA2002-25-5-B/LH195	7.56	1.30
LAMA2002-42-B-B/LH195	8.23	1.15
LAMA2002-46-3-B/LH195	7.37	1.40
LAMA2002-58-1-B/LH195	5.55	1.58
DKC66-80	9.19	1.45
DKC69-70	9.60	1.39
P31B13	10.18	1.78
P32R25	9.40	1.71
LH195 x LH210	9.59	1.00
DKC69-72	9.28	1.55
SCR42 x Tx772	5.93	0.93
LSD (0.05)†	1.24**	0.73
Overall Mean	8.07	1.28
LAMA TC Mean	7.60	1.22
U.S. Hybrid Mean	9.02	1.40

† Fisher's least significant difference, use to compare individual hybrids.

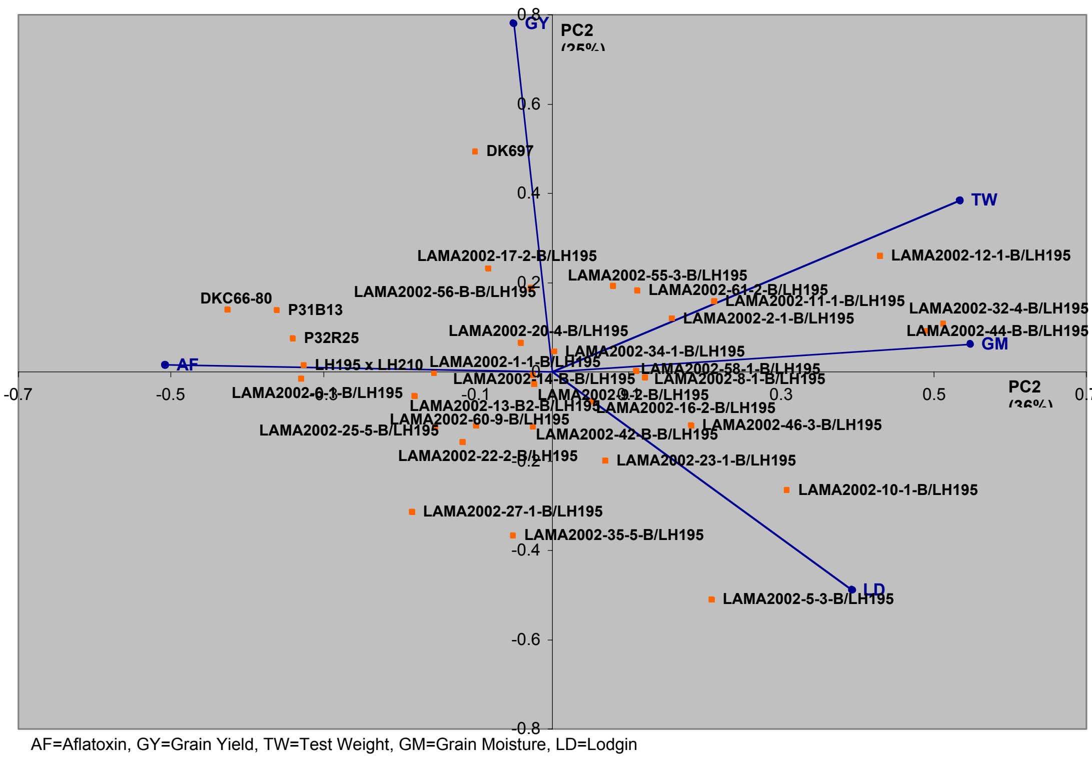

Figure 54. Singular value decomposition biplot of trait means in Weslaco for complete set of LAMA testcrosses and U.S. hybrids.

VITA

Brett A. Ochs was born on February 2, 1981, and raised on the family farm in Tuscola, Illinois. Brett graduated with an A.S. in agriculture from Parkland College in August 2003 and a B.S. in crop sciences from the University of Illinois in August 2003. He then came to Texas A&M to do research in the Maize Breeding and Genetics Laboratory and graduated with a M.S. in plant breeding from Texas A&M University in August 2005. After graduation from Texas A&M, Brett pursued a Ph.D. at Purdue University, researching in the Small Grains Program.

PERMANENT ADDRESS:

1151 N. County Road 1050 E.
Tuscola, IL 61953
(217) 253-4643
ba_ochs@yahoo.com